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MINUTES AND PROCEEDINGS

Of the Twenty-ninth Meeting of the

ARMED FORCES - NRC VISION COMMITTEE

November 16-17, 1951

U.S. Naval Submarine Base
New London, Conn.

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Dept. of Ophthalmology
Columbia University,
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Washington 25, D. C.

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844 North Rush Street
Chicago 11, Illinois

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Physics Department
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St. Louis 3, Missouri
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Minutes of the Twenty-ninth meeting

November 16-17, 1951

U. S. Naval Submarine Base
New London, Conn.

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COMMENTS ON THE REPORTS AND DISCUSSION CONCERNED WITH VISUAL ACUITY REQUIREMENTS FOR SUBMARINE ENLISTED PERSONNEL

Dr. Hedwig S. Kuhn

a. Page 34, Paragraph 6. The emphasis we felt was the most important of all was missed, namely that each and every time that we talk about "Visual acuity" we must indicate whether we are talking about distance acuity or near acuity. The paragraph reads that "visual acuity requirements ----- indicate that a visual acuity of 20/40 in each eye is tolerable for these people." It must be understood that in this instance we are talking only about distance acuity, as 20/40 is not tolerable for near acuity.

b. In this paragraph the statement is made that "incident to stress and fatigue, visual acuity is expected to deteriorate." There again the emphasis must be that distance vision rarely deteriorates if ever under stress and strain, but near vision for a man operating radar dials and charts definitely deteriorates (temporarily of course) under stress and strain IF these individuals are very far sighted. The danger of such a fatigue factor in the individuals operating radar and so forth is very serious. Actually much more serious than any disturbance of distance vision.

c. Page 35, Paragraph 3. Statement is made that "Dr. Kuhn considers 20/30 to constitute an industrial hazard." This is simply not true, I never said that and never meant it. It contradicts everything else that I have ever said to anyone. There is no single acuity that constitutes a hazard. I did say as we indicated an Annapolis, that a vision of 20/40 OU uncorrected could be hazardous for people working at a distance on important items and dangerous jobs.

d. The final statement made by Capt. Willmon, unfortunately failed to focus attention on what has never been recognized as important as it should be, namely that there are two separate types of visual performance that must be considered in evaluating visual capacity for job demand. These are:

   a. Distance visual requirements.
   b. Near vision requirements.

SUMMARY OF THE DISCUSSION AT THE CONFERENCE

ON

VISIBILITY AT HIGH ALTITUDES

Those present at the visibility conference were the following: Vision Committee members, including Dr. H. R. Blackwell, Commander Dayton R. E. Brown, Col. Victor A. Byrnes, Mr. C. A. Douglas, Dr. S. Q. Duntley, Lt. Col. J. R. Grunwell, Dr. E. O. Hulburt, Dr. D. E. Macdonald, Group Captain J. C. McCulloch, Mr. W. E. K. Middleton, Dr. H. H. Neuberger, Dr. Brian O'Brien, Captain C. W. Shilling, Dr. Richard Tousey. Others present were Mr. A. B. Alexander, Offutt Air Force Base, Dr. William H. Allen, Maxwell Air Force Base, Mr. Chester H. Baker, Canadian Defense Research Medical Laboratories, Toronto, Professor Edward A. Bott, University of Toronto, Dr. Paul A. Cibis, Randolph Field, Dr. Louis Elterman, Air Force Cambridge Research Laboratory, Dr. Charles H. Smiley, Brown University, Dr. Rodney H. Smith, Offutt Air Force Base, Dr. K. Aa. Strand, Northwestern University.

Dr. Blackwell, acting as Chairman of the working group on visibility at high altitudes of the Vision Committee, called the visibility conference to order. He explained the general purpose of the meeting which was to provide recommendations to the Air Force concerning their visibility problems encountered in planning high altitude flights in the northern latitudes. Four kinds of problems are involved: (a) visibility from air to air; (b) visibility from air to ground; (c) visibility from ground to air; (d) visibility of stars to be used in navigational purposes.

The Air Force recognizes the fact that during certain hours on certain days of the year visibility is sufficiently restricted by reason of low sky brightness that detection of our aircraft is not to be expected. The Air Force would like to have operational planning charts which would tell them during which hours visual detection would be possible at only short ranges and the hours during which detection would be possible at somewhat longer ranges. Dr. Blackwell suggested that the discussion might well proceed by considering each of the four problems separately. Dr. Blackwell asked members of the conference to discuss the status of present knowledge of each of the problems in turn and the anticipated information required to provide adequate visibility predictions under each of the four circumstances.

Discussion of the problem of air to air visibility was undertaken. It was agreed that the atmospheric optics aspect of this problem is the simplest of the four because one is concerned with a horizontal stratum of air which will be reasonably uniform in optical properties. Furthermore, at high altitudes, there is very little scattering along an horizontal path and hence, the atmosphere does not enter into the visibility problem to as great an extent as is the case in other visibility problems.

It was agreed that in order to predict visibility from air to air, one would need to know the brightness and pattern of the sky background for the target, the illumination of the target, the angular velocity of the target, and the pattern of light and shadow on the surface of the target. The effect of each of these variables upon the detection threshold of the human eye must then be known.

Various members of the conference commented on the knowledge we have concerning the brightness of the sky at high altitudes. The research being undertaken by Commander Norman Lee Barr of the Naval Medical Research Institute was discussed. It was agreed that the measurements Commander Barr is making are highly desirable. Because quantitative information from Commander Barr's measurements is not available, it was not possible for the members of the conference to discuss the measurements being made.

There was some discussion of the extent to which brightness of the sky at high altitudes may be predicted on the basis of molecular scattering theory. Dr. Hulburt took the position that although the theory is clearly not entirely correct, at least orders of magnitude can be established from the theory and from experimental measurements which have been made. These orders of magnitude may be expected to be very valuable in giving the Air Force at least tentative operational planning charts. Dr. Hulburt agreed to attempt to collate the present measurements on sky brightness so that tentative charts could be developed at the earliest possible date.

Commander Brown described the charts which the Bureau of Ships has constructed representing the illumination from the sun and sky as a function of time oft the year and latitude. Commander Brown stated his opinion that it should be possible to extend the data to high altitudes by compensating for the difference in the position of the sun with respect to the target encountered at high altitudes in contrast to on the ground.

There was some discussion of the proper visual thresholds to be employed for solution of the air to air visibility problems at high altitudes. Dr. Blackwell emphasized that there is at present no satisfactory information concerning the visibility of a target which is partially in light and partially in shadow so that there are both positive and negative contrasts in the same target. Dr. Blackwell also stated that it is not possible at present to estimate the effect of target motion upon detection threshold. Furthermore, data do not exist for sufficient portions of the visual field to permit one to compute the probability of detection when the position of the target is not known. Other variables which need to be investigated include: (a) the effect of information concerning the target on its detection threshold and (b) the effect of non-uniformity of background brightness such as produced by the horizon line and cloud structures. Investigation of these variables is required if a complete solution of the air to air visibility problem is to be obtained. Dr. Blackwell suggested that order of magnitude experiments should be conducted and more precise experiments conducted in so far as there is time and financial assistance.

There was considerable discussion as to whether one could ever expect to predict sky brightness and illumination data in the Arctic from corresponding data collected in other parts of the world or from theories. Dr. Smiley described some of the peculiar brightness phenomena he has observed in the Arctic regions. Dr. Smiley expressed his belief that it will not be possible to predict Arctic sky brightness and illumination from measurements made in more southerly latitudes. The importance of ground cover was emphasized. Furthermore, the peculiar temperature inversions which occur in the Arctic lead to brightness conditions which cannot be found in other regions.

There was some discussion of the difficulties involved in predicting visibility from air to ground. Because of stratification of the atmosphere, visibility along a slant path is an extremely difficult problem. Dr. Macdonald described the interest of the Optical Research Laboratories at Boston University in this problem and reported that certain kinds of experiments are being carried out with reference to this problem. It was the concensus of opinion that this problem is extremely difficult and is not of the greatest interest to the Air Force in connection with high altitude flights over the polar regions. For this reason, the conference did not consider this problem in the same detail as it had considered the problem of air to air visibility.

The same difficulties involved in air to ground are involved in ground to air visibility. Here again, the greatest interest of the Air Force in connection with the polar flights is air to air visibility since it may be expected to be considerably better than ground to air visibility.

The problem of the visibility of stars for use in navigational purposes was discussed by members of the conference. The work done by Dr. Hulburt and Dr. Tousey was con-

sidered to provide very good data for use in connection with the Air Force problem. Dr. Tousey agreed to attempt to organize this information in such a way that the Air Force could utilize it.

The conference next considered the form of the recommendation which should be made to the Air Force. Colonel Byrnes stated that the Air Force would like a recommendation indicating what kind of information is required in order to solve the visibility problems under question and suggestions as to what persons or institutions might be interested in undertaking the necessary research to provide the desired answers. After considerable discussion, a recommendation was prepared which is contained in the report presented by Dr. Blackwell before the main Committee meeting. This recommendation is to be found in the Proceedings in the next item.

REPORT OF THE CONFERENCE
on
VISIBILITY AT HIGH ALTITUDES

H. Richard Blackwell, Chairman

A conference on visibility at high altitudes was organized in order to provide the Air Force with recommendations concerning the visibility of long-range bombers at high altitudes in the Arctic. The conference consisted of members of the Vision Committee, representatives of the Air Force and the Navy, and liaison representatives of the Canadian Department of Defense.

The nature of the problem of predicting visibility of long-range bomber aircraft under the conditions of interest was considered in some detail. Members of the conference discussed the present status of scientific knowledge pertinent to each aspect of the problem, reported current research relevant to the problem and indicated the general direction of additional research needed to provide the most adequate answers possible. As a result of this discussion, a general recommendation was developed by the conference concerning the status of and general direction for visibility research. The recommendation may be stated as follows:

(1) The visibility problems of the Armed Forces are of such scope and urgency during the present national emergency that steps should be taken immediately to produce the best answers of which the state of the science of visibility prediction is capable, and to initiate at once experimental procedures designed to fill those gaps which obstruct the production of the needed answers.

(2) The production of the above answers requires a central laboratory staff of full time problem solvers, directed by an advisory panel of the principal specialists in the visibility of military and naval targets. This staff should deal with visibility problems from the entire Department of Defense and should serve as an officially recognized central clearing-house for pertinent data and problems. The attention of the staff should be directed at the outset to the problems of the Strategic Air Command, and to other problems of the Air Force, Army, and the Navy.

(3) It is recommended that Professor S. Q. Duntley of the Massachusetts Institute of Technology establish the central laboratory described above.

Discussion:

The Chairman called for a discussion of the recommendation of the visibility conference. It was the concensus of the discussion that the recommendation be approved by the Vision Committee. A motion was passed accepting the recommendations of the visibility conference and directing that they be transmitted to the military liaison representatives of the Vision Committee.

AN EXPERIMENTAL DETERMINATION OF SOME ISO-COLOR LINES IN COLOR-DEFICIENT VISION[1]

Alphonse Chapanis[2]

The Institute for Cooperative Research,
The Johns Hopkins University

I. INTRODUCTION

A. Background of the Problem

People with defective color vision do not see as many distinct colors as do people with normal color vision. Thus, many colors which look markedly different to normal eyes will look identical to a dichromat or an anomalous trichromat. In the last 300 years, hundreds of studies have been done on these "confusion colors," as they are sometimes called, but nearly all of these early studies made use of color samples which cannot be precisely specified. As a result, there is still little information concerning exactly which colors will appear identical to a color-deficient observer.

The best known and most useful data on the color confusions of dichromats are those shown in Figure 1. The diagram on the left shows iso-color lines for protanopes; the one on the right for deuteranopes. Colors which lie in the zone between any two adjacent lines are supposed to appear identical to the appropriate kind of color-deficient person, provided that the intensities are equated for the person concerned.

The diagrams in Figure 1 are based on data originally collected by Pitt (4) on five protanopes and six deuteranopes. Pitt determined the proportions of red and blue light required to match the spectral hues (dichromatic coefficient curves), the luminosity function, wavelength discrimination function, and blue-green neutral point (the spectral hue which matches white) for all his subjects. From the average data, he then computed iso-color lines and plotted them on a color diagram. Later, Judd (2) transformed Pitt's iso-color lines into the ICI system, and these are the diagrams shown in Figure 1.

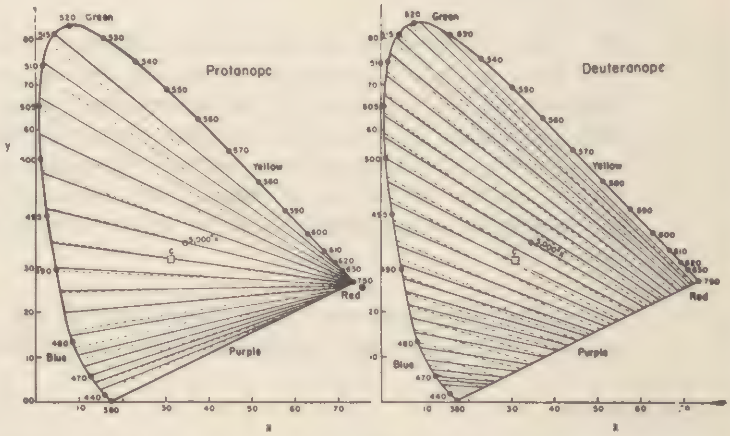

Figure 1. Iso-color lines for protanopic (left) and deuteranopic (right) vision as computed by Judd from Pitt's original data. The interrupted lines fit the data closely. The solid lines are copunctal at x = 0.747, y = 0.253 for protanopes and at x = 1.00, y = 0.00 for deuteranopes.

For our purposes, it is important to note that the diagrams in Figure 1 have been derived by computation from spectral measures. So far as we are aware, there has been only one determination of iso-color lines with surface colors which can be precisely specified. This is a study by Farnsworth (1) which has been reported in abstract, but never published.

[1] This research has been done under Contract N5-ori-166, Task Order I, between the Special Devices Center, Office of Naval Research, and The Johns Hopkins University.

[2] I should like to acknowledge the competent assistance of Miss Rita M. Halsey who has collaborated with me in this study and has been primarily responsible for the many hours of tedious testing and tabulating required by it.

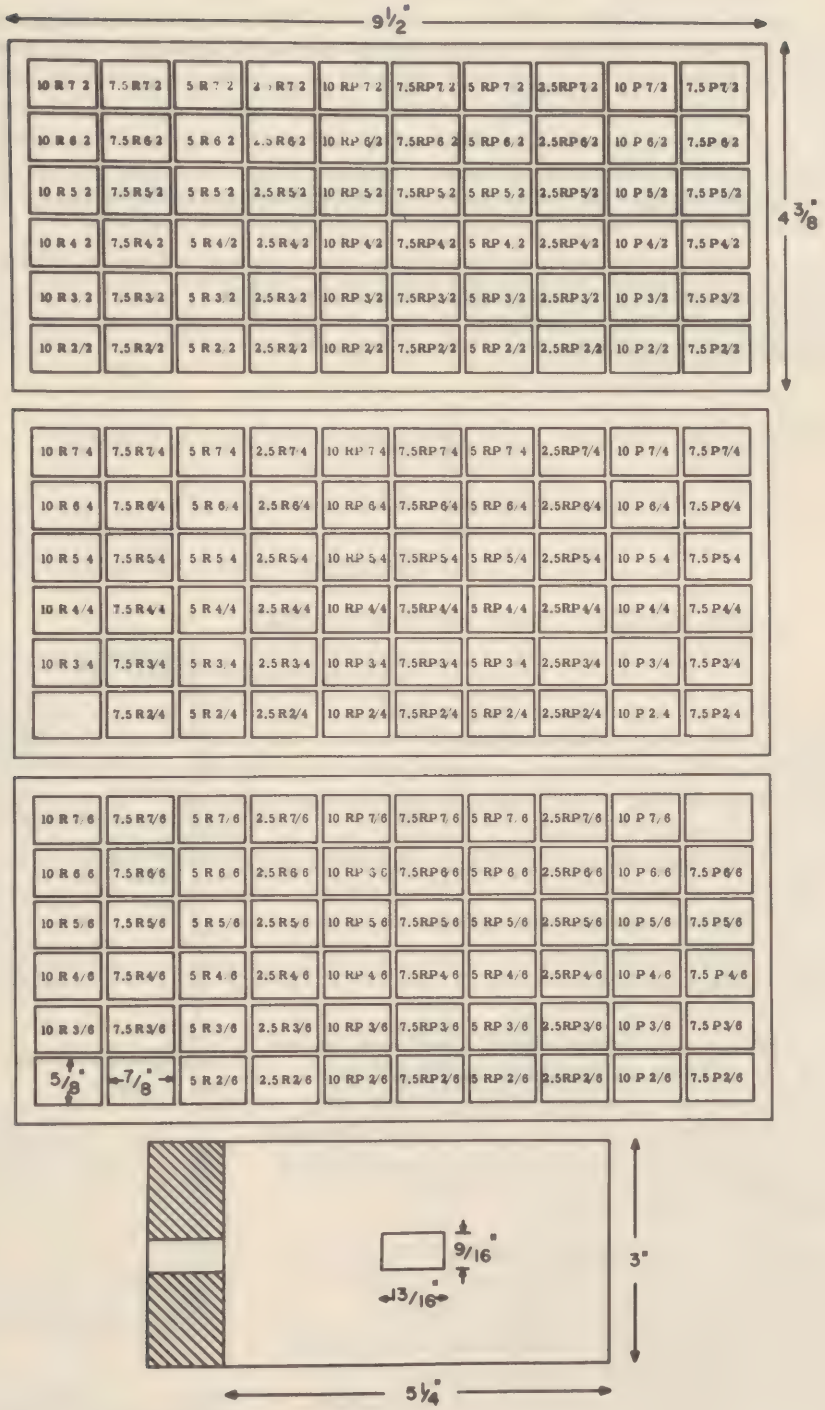

Figure 2. The three large rectangles show the arrays of hues--one at each chroma-level--from which subjects selected matches. Each of the standards was made up as a mask (the small rectangle below) which the subject could move over the array.

B. Statement of the Problem

This investigation determined directly some of the color confusions made by both dichromats and anomalous trichromats in matching Munsell papers. We have chosen a practical and common situation--one in which the subject is called upon to make matches between colors which appear different to normal eyes. Specifically, subjects were required to select from a wide assortment of red, red-purple, to purple hues those which matched certain neutral and blue-green Munsell papers. Thus, this investigation is concerned with isocolor lines in the blue-green, neutral, and red-purple areas (See Figure 3).

To obtain as much information as possible concerning individual differences in color matching, 47 unselected color-deficient subjects were used. Unlike many investigations, we are not dealing here with a few carefully selected, ideal observers, but rather with a wide variety of color-deficient observers.

II. PROCEDURE

A. Determination of Confusion Colors

1. Materials

The eight standard Munsell colors matched by the subjects were:

Neutral 3/	2.5 Blue-green 3/6
Neutral 4/	2.5 Blue-green 4/6
Neutral 5/	2.5 Blue-green 5/6
Neutral 6/	2.5 Blue-green 6/6

Each standard color was made up as a 3 by 5 1/4 inch mask, with a hole 9/16 x 13/16 inches in its center, and provided with a handle so that the subject could position it anywhere over the stationary chart of comparison colors (See Figure 2).

The comparison colors from which matches were selected were 5/8 by 7/8 inch samples mounted on three large pieces of white cardboard, as shown in Figure 2. Each arrangement was at a constant chroma (saturation) level and included hues 10 Red through 7.5 Purple at value (brightness) levels 2/ through 7/.

All of the Munsell papers used in this study have been specified in terms of the ICI system, and their locations on the ICI diagram are shown in Figure 3. The colors on the three parts of the graph correspond to those on the three cardboard sheets in Figure 2. The ICI specifications shown in the figure, and used in the calculations, are those given for the colors viewed under illuminant "C".

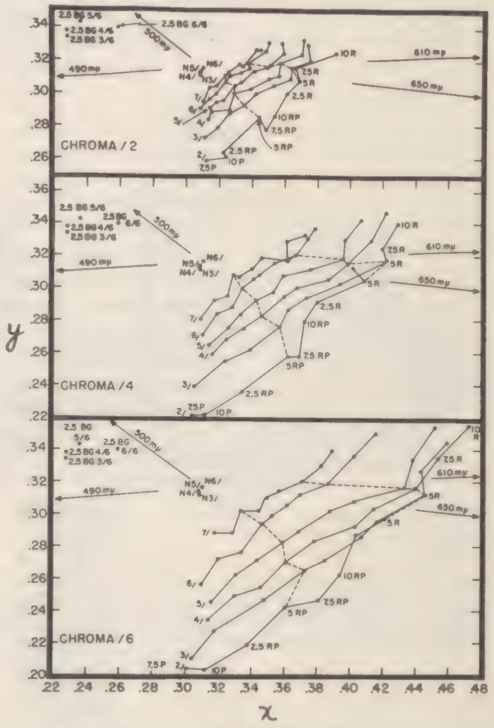

Figure 3. Sections of the ICI diagram showing the locations of the Munsell hues in Figure 2. Also shown are the locations of neutral and blue-green standards.

2. Method

Each subject was required to make 24 matches between the standard colors and the comparison colors: each standard was matched with some color on each of the three

constant-chroma charts. The 24 combinations of standard colors and constant-chroma charts were presented in random order. The subject was allowed to move the mask of the standard color until he found the sample on each chart which provided the best match. The position of the subject's head was not held constant, but a viewing distance of about 18 inches was maintained. No time limit was imposed. In cases of hesitancy, the subject was urged to select the best match although no match was completely satisfactory. He was also asked to rate each match as excellent, good, fair, or poor.

All observations were made monocularly, the unused eye being covered with a light-proof guard. The eye selected by the subject was used for all subsequent tests.

B. Supplementary Measures

(1) A battery of 82 pseudo-isochromatic plates was administered to each subject under standard conditions.

(2) Photopic thresholds for red light were determined to aid in classifying the subjects.

(3) A Beckman spectrophotometer provided the source of light for the determination of neutral points in the blue-green portion of the spectrum.

C. Processing the Data

1. Calculation of match lines

For every standard and blue-green color there were three color matches--one at each chroma (/2, /4, /6) for every subject. On the assumption that the three color points should fall on a straight line on the ICI diagram, straight lines were fitted through them by a statistical technique which provided that the sum of the squared deviations (perpendicular distances from the points to the line) be a minimum. The line was made to pass through the locus of the standard color.

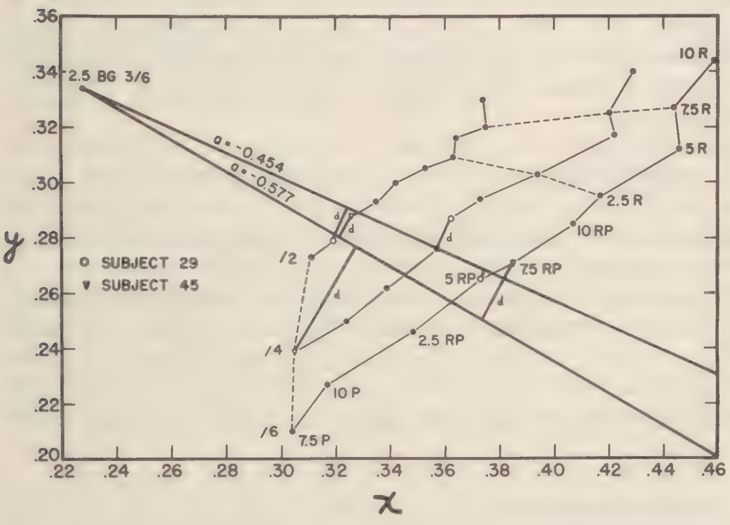

Figure 4. Section of the ICI diagram showing colors selected by two subjects as matches for 2.5 BG 3/6. The colors available at value 3/ for each chroma level are shown by dots. $\underline{d}$ is the perpendicular distance from the color locus to the best-fitting straight line fitted through the points so that Σd^2 is minimized. The slope of the best-fitting straight line is given by $\underline{a}$. The line for Subject 29 is the worst we accepted as a fair fit, that for Subject 45 is a poor fit.

Figure 4 illustrates the technique for matches made with one of the standard colors by two different subjects. These subjects made matches with 2.5 BG 3/6 as follows:

	Subject 29	Subject 45
at chroma /2	10 P 3/2	2.5 RP 3/2
at chroma /4	7.5 RP 3/4	7.5 P 3/4
at chroma /6	5 RP 3/6	7.5 RP 3/6

These colors, together with the other colors available at value 3/, are shown on the ICI diagram in Figure 4. $\underline{d}$ is the perpendicular distance from the point to the line, which is the best fitting straight line through the color points when Σd^2 is a minimum. Each line originates at the locus of the standard color.

When each best-fitting straight

line and its color points was plotted on the ICI diagram, it was obvious that some of the lines were poor fits for the data. (See, for example, the data for subject 45 in Figure 4.) For this reason, the $\sum d^2$ for each line was computed as an indication of the goodness of fit and was used to classify each line as a good, fair, or poor fit. Figure 5 illustrates two good fits. The line for subject 43 is one of the very good fits obtained (there are, however, 54 lines which fit even more satisfactorily). The line for subject 17 has the largest $\sum d^2$ accepted as a good fit. Subject 29's match line shown in Figure 4 is the worst fit accepted as fair. The line for subject 45(Figure 4) is one of the worst obtained and is rated poor. Descriptively, it is characteristic of good-fitting lines that the color matches made by the subject do not deviate from the line by more than one hue-step. Fair-fitting lines are characterized by color matches which may deviate by as much as one hue step at two different points. The category of poor fits applies to cases where the three colors cannot reasonably be described as lying in a straight line.

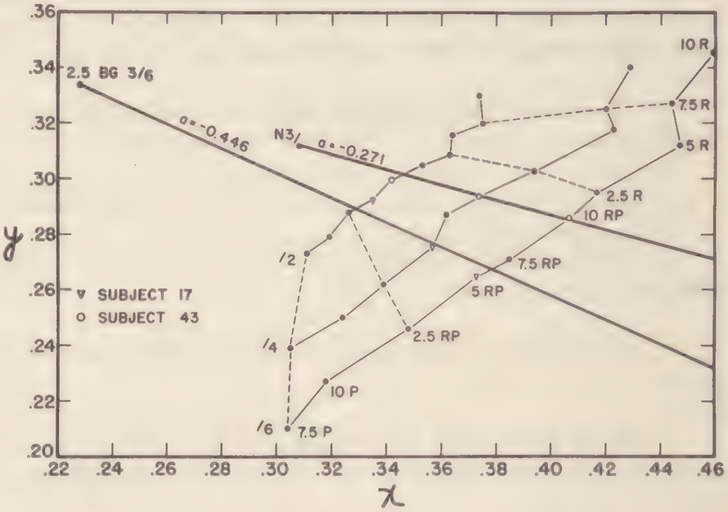

Figure 5. Section of the ICI diagram showing the colors selected by Subject 17 as matches for 2.5 BG 3/6, and by Subject 43 as matches for Neutral 3/. The line for Subject 17 is the worst we accepted as a good fit; that for Subject 43 is a very good fit.

The figure used to describe each set of color matches is the slope of the best-fitting line, whose origin is at the locus of the standard color. The slopes of the match lines in Figures 4 and 5 are given by a.

2. Evaluation of brightness relationships

The ICI Y term is a measure of the relative brightness of each sample. Since only six value levels were used, the distribution of available Y's is not continuous, but rather a series of discrete groupings around .03, .07, .12, .20, .30 and .43. Since these are coarse steps, Y-values for particular matches by any subject tend to be erratic. However, as we shall see later, average Y-values acquire some stability.

III. SUBJECTS

Forty-seven randomly-selected color-deficient men were tested. They were volunteers who knew of their deficiency or were curious to know if they were color deficient. We accepted and tested anyone who applied at the laboratory, rejecting for complete testing only those who had normal color vision. Thirteen normal subjects, however, were retained as a control group.

Several criteria were used in classifying subjects and the final distribution is as follows:

7 protans with severe defects
9 protans with mild defects
10 deutans with severe defects
21 deutans with mild defects
13 color normals

IV. RESULTS

A. Munsell Notations of the Matches

Inter-group differences can be summarized in Munsell terms by combining selections at all three chroma levels and with all four values of the standard colors, ignoring brightness differences. The results appear in Figure 6.

As noted earlier, we asked the subject to rate each match according to how it appeared to him. These matches were supposed to have been graded in terms of four descriptive terms: excellent, good, fair and poor. In actual practice, the subjects usually amplified their descriptions and used such additional terms as: perfect, very poor, terrible, and awful. We recognize that these terms mean different things to different people, but it is probably safe to assume that matches rated excellent and perfect are about as good as one can obtain with Munsell samples.

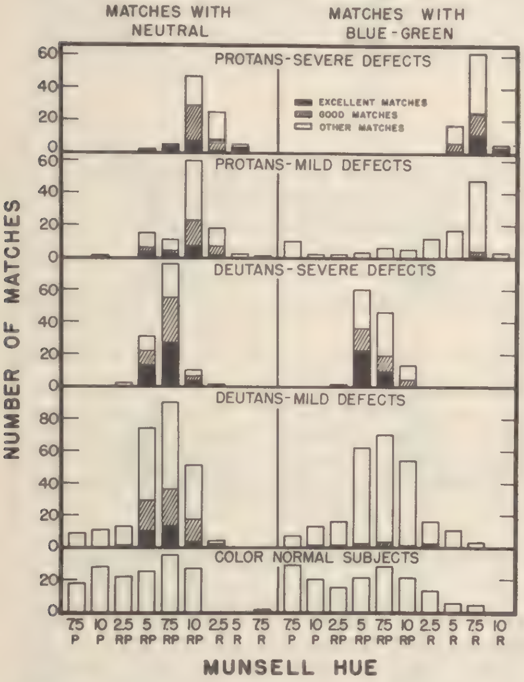

Figure 6. Munsell hues selected as matches for the neutral and blue-green standards by each group of subjects. Data for all values and chromas are combined. The subjects' own ratings of the matches are shown by the solid, cross-hatched, and open areas.

Of the 1,128 matches made by the color-defective subjects, 142 matches were rated excellent and are shown in solid squares in Figure 6. Also shown there are 221 matches rated good by the subjects. The remaining 765 matches were rated fair, poor, or otherwise unsatisfactory. Table 1 gives the complete list of excellent and good matches.

Figure 6 shows that in the case of matches with neutral, there is overlap between the distributions of matches made by the protans and deutans. In spite of this, there is a clear difference of one color step between the modal matches of the two groups. The subjects with mild defects made matches resembling those chosen by the more seriously-deficient subjects, but the former show a greater range of choices. The normal subjects show the greatest variability and lack a definite modal choice.

The difference between protan and deutan choices is accentuated in matches with the blue-green standards, protan matches centering at 7.5 Red, while deutan matches center at 5 Red-purple. Again, the subjects with mild defects selected the same colors as did those with severe defects, but the former show more spread. And again the matches by normals are greatly scattered.

The differences between protan and deutan matches are more pronounced when only the excellent and good matches are considered. Such matches also show better agreement between the subjects with mild and severe defects. Finally, note that subjects with severe defects used a much higher proportion of good and excellent ratings than did those with mild defects.

Although the trends in Figure 6 are consistent, detailed analysis of the data revealed some shifts in hue at different chromas and values. For example, in matches against 2.5 BG 5/6 at chroma /2 the deutans most commonly selected 5 RP as the best match (See Table 1), but at chroma /6, they most commonly selected 7.5 RP as the best match. Such shifts in the most frequently-selected hues are due in part to irregularities in the positions of Munsell hues in ICI space (See Figure 3). For this reason, the agreements and disagreements between matches made by the different groups are best evaluated in terms of the ICI system.

B. Slopes of Match Lines

The slopes of the straight lines we computed are, of course, tangents, and a tangent scale is a non-linear transformation of an angular scale. For the kind of data we have here, with variations both in the X- and Y-dimensions, it seemed to us most appropriate that the non-linearity of the tangent scale be corrected in all our calculations. For this reason, average slopes were computed in this way: Each slope was expressed as its angular equivalent, the angles were averaged, and the average angle was then reconverted into a tangent. The last figure is the one we have used in subsequent graphs. Similarly, the tangent scale at the bottom of Figure 7 is spaced according to equal angular steps.

Inspection of the means for each group at different values showed that there is very little change in slope for the different values of the standard colors. Therefore, to show

TABLE I

Matches which were rated good and excellent for each of the standard colors by the two groups of color-deficient subjects. The first numeral following each Munsell hue designation shows the number of subjects who rated a particular match excellent; the numeral in parentheses shows the number of additional subjects who rated a particular match good.

Standards	Chroma /2		Chroma /4		Chroma /6	
	Protans	Deutans	Protans	Deutans	Protans	Deutans
N 3/	5RP2/2 1(1) 10RP3/2 1(4) 2. 5R3/2 -(2) 5R3/2 2(1)	5RP2/2 -(2) 5RP3/2 -(4) 7. 5RP3/2 1(5) 10RP2/2 -(2) 10RP3/2 -(2)	2. 5R2/4 -(1) 2. 5R3/4 -(1) 2. 5R4/4 -(1) 7. 5R2/4 -(1)	7. 5RP3/4 3(3) 10RP3/4 6(7) 2. 5R2/4 -(2)	10RP2/6 -(2) 2. 5R2/6 -(1) 2. 5R3/6 1(1) 2. 5R4/6 -(1)	7. 5RP3/6 -(3) 10RP2/6 -(1) 10RP3/6 -(1)
N 4/	7. 5RP4/2 1(-) 10RP4/2 4(3) 2. 5R4/2 -(2) 2. 5R5/2 -(1)	2. 5RP4/2 -(1) 5RP4/2 -(1) 7. 5RP4/2 7(8) 7. 5RP5/2 1(-)	10RP4/4 -(1)	5RP3/4 -(1) 5RP4/4 -(1) 7. 5RP4/4 4(5) 10RP4/4 -(2)	10RP3/6 -(1) 10RP5/6 -(2) 2. 5R5/6 -(1)	7. 5RP4/6 4(1) 10RP4/6 -(1)
N 5/	5RP5/2 -(2) 7. 5RP5/2 2(-) 10RP5/2 -(7) 2. 5R5/2 1(1)	5RP5/2 1(3) 7. 5RP5/2 11(8)	10RP5/4 3(4)	5RP5/4 1(1) 7. 5RP5/4 5(7)	7. 5RP5/6 -(1) 10RP5/6 1(1) 10RP6/6 -(1)	7. 5RP5/6 3(3)
N 6/	5RP6/2 3(1) 7. 5RP6/2 2(2) 10RP6/2 4(3)	5RP6/2 12(6) 7. 5RP6/2 -(3)	7. 5RP6/4 -(1) 10RP5/4 -(1) 10RP6/4 -(5) 10RP7/4 -(1)	5RP6/4 6(7) 7. 5RP6/4 -(3) 10RP6/4 -(1)	10RP6/6 1(1) 10RP7/6 -(1)	5RP6/6 3(2) 7. 5RP6/6 1(2)
2. 5BG3/6	5R3/2 -(1) 7. 5R4/2 -(1) 10R4/2 1(-)	5RP3/2 1(-) 7. 5RP3/2 3(3) 10RP3/2 -(1)	5R4/4 -(1)	5RP3/4 4(-) 7. 5RP3/4 -(1) 10RP3/4 -(1)	5R4/6 -(2)	5RP3/6 2(4) 7. 5RP3/6 -(2) 2. 5R3/6 -(1)
2. 5BG4/6	7. 5R5/2 1(3)	10P4/2 -(1) 5RP4/2 3(3) 7. 5RP4/2 1(1)	7. 5R5/4 1(3)	2. 5RP4/4 -(1) 5RP4/4 1(-)	5R5/6 -(1)	5RP4/6 2(2)
2. 5BG5/6		5RP5/2 3(3) 10RP5/2 -(1)	7. 5R6/4 -(4) 10R6/4 -(1)	5RP5/4 -(2) 7. 5RP5/4 1(-)		5RP5/6 1(-) 7. 5RP5/6 3(3)
2. 5BG6/6	7. 5R7/2 1(3)	5RP6/2 2(2) 10RP6/2 -(1) 2. 5R6/2 -(1)	7. 5R7/4 6(1) 10R7/4 1(-)	7. 5RP6/4 -(1) 10RP6/4 -(1)	5R7/6 1(-) 7. 5R7/6 3(2)	5RP6/6 3(-) 7. 5RP6/6 1(2)

differences between groups, and between the colors of the standards, the slopes for all values have been grouped together in one distribution for each group, as shown in Figure 7.

There are three important points to note about the distribution of fits in Figure 7. First, the proportion of good straight lines which can be fit to the color matches is higher for the subjects with severe defects than for those with mild defects (61. 8 as compared with 40. 8 per cent). The color normal subjects, on the other hand, had a very low proportion of good fits (16. 3 per cent). In addition, there were many more good fits in the matches made against neutral standards as compared with those against blue-green standards (58. 5 as compared with 38. 3 per cent for the color-defective subjects). Finally, there do not appear to be any outstanding differences between the protans and deutans in the proportion of good fits (60. 7 as compared with 62. 5 per cent for the cases with severe defects).

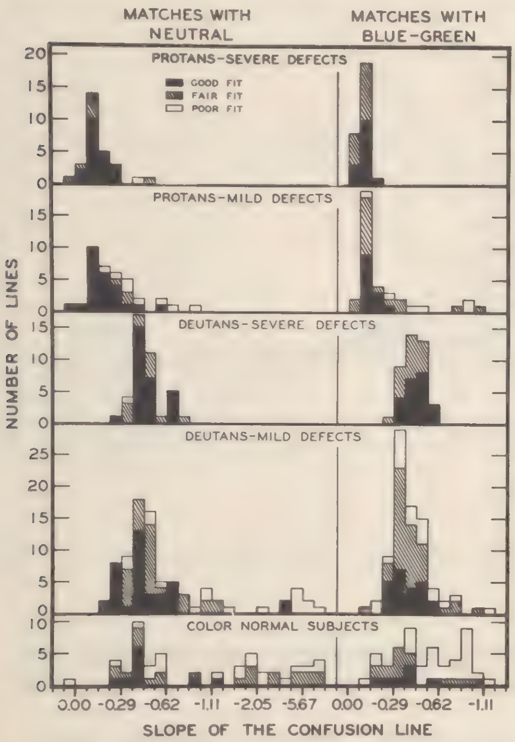

Figure 7. Slopes of the best-fitting straight lines computed for the three color matches made by each subject. Data for all four value (brightness) levels are combined. The goodness of fit of each line to the data is indicated by the solid, cross-hatched, and open areas.

An analysis was made of the directions of the deviations of the color points from the best-fitting lines. Although some departures from linearity were found, they varied from standard to standard, and for various groups of subjects. No single type of curved line could be found to fit the data more accurately and consistently than the straight lines. Therefore, we feel justified in assuming that straight lines best describe the data.

There are three important things to note about the slopes in Figure 7. First, within any group there is a sizeable amount of variability. The variability is least for the subjects with severe defects, and greatest for the normal subjects. Second, the mean slopes for subjects with mild defects are approximately the same as the means for those with severe defects. Third, there is a large difference between the mean slopes of protans and deutans. In fact, if we consider the matches made with blue-green standards by subjects with severe defects, there is no overlap at all in the distributions.

TABLE II

Mean slopes of good fitting straight lines for matches by subjects with severe defects.

Standard	Protans	Deutans
N 3/	-. 114	-. 450
N 4/	-. 123	-. 388
N 5/	-. 124	-. 385
N 6/	-. 168	-. 556
2. 5 BG 3/6	-. 0664	-. 455
2. 5 BG 4/6	-. 0723	-. 346
2. 5 BG 5/6	-. 0793	-. 419
2. 5 BG 6/6	-. 109	-. 464

Mean good-fitting lines for subjects with severe defects are shown in Figure 8, and the slopes for these lines are listed in Table II. In the case of the deutans, the lines drawn through the neutral and blue-green standards are intermingled and not clearly separable. For the protans, however, the lines through the blue-green standards are in every case above those drawn through the neutral standards. A disturbing feature of this picture is that the blue-green and neutral lines meet in the blue-green part of the diagram, and not in the red part, as might have been expected on the basis of Judd's diagram (Figure 1). Although we cannot account for this at present, we feel that our empirical data, especially the lines drawn through the blue-green standards, are trustworthy.

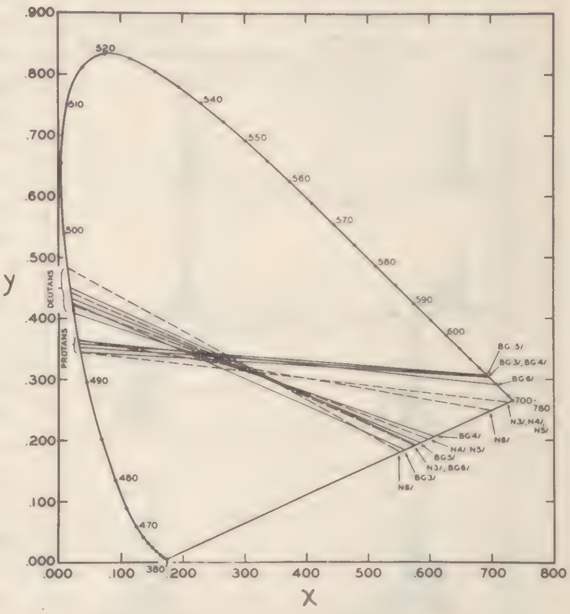

Figure 8. Mean good-fitting lines for subjects with severe defects. Interrupted lines are for the neutral standards; solid lines for the blue-green standards.

As is apparent from Figure 1, the isocolor lines computed by Judd meet at a common point. For protanopes, this point is at x = 0.747, y = 0.253. In the case of deuteranopes, there are two possible points--the one at x = 1.00 y = 0.00 is, according to Judd, theoretically better than the one at x = 1.08, y = -0.08 which, however, fits Pitt's data better. In Figures 9 through 16 we have selected those copunctal lines (1 for the protans, 2 for the deutans) which in every case pass through the particular standards we used.

From Pitt's data, Judd (3) has derived standard response functions and equations which predict the locations of all Munsell hues in luminosity and chromaticity coordinates for dichromats. Using these equations, we have computed the protanopic and deuteranopic coordinate values for all our colors. For protanopes and deuteranopes separately, we selected, at each chroma, that Munsell hue which had chromaticity-coordinate values most nearly approximating those of each standard. If the luminosity coordinate values were not markedly discrepant, we accepted these hues as providing the best match that could be obtained from our array of colors. To these predicted matches we fit straight lines using the same procedure as in the main part of the experiment. These are the dotted lines in Figures 9 through 16.

The average good-fitting lines which we used in Figures 9 through 16 are open to some criticism, because we forced the subject to make matches even when he objected that there were no good ones. For this reason, we have also calculated for the pooled data of Table I best-fitting straight lines for only those matches which the subjects themselves rated excellent. These lines are also shown in the figures. It is gratifying to note that, in almost every instance, the lines fit to the excellent matches are virtually identical with the mean good-fitting lines discussed above.

On the whole, the various lines computed for the deutan subjects show substantial agreement, with the possible exception that, in several instances, lines copunctal at x = 1.08, y = -0.08 seem to fit the empirical data less well than those copunctal at x = 1.00, y = 0.00.

For the protanopes, the lines derived from the various measures for matches with the neutral standards show close agreement. For matches with the blue-green standards, on the other hand, there are two obviously different sets of lines--the lines fit to our data fall considerably above those predicted by Judd. The extent of the disagreement may be

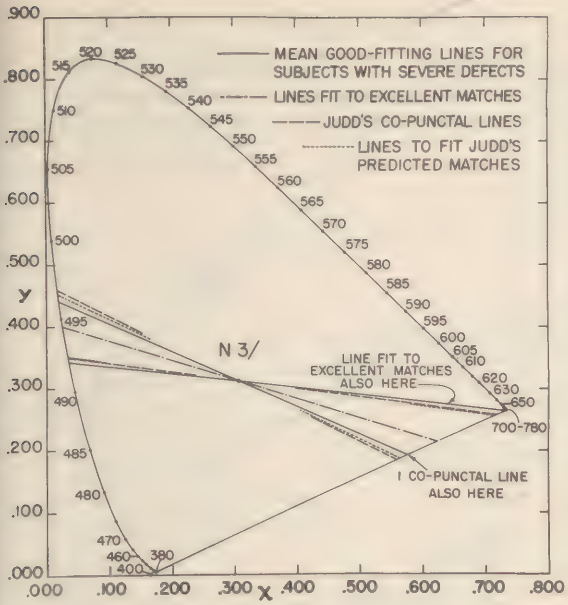

Figure 9. Empirical and theoretical iso-color lines for N 3/ computed according to several techniques.

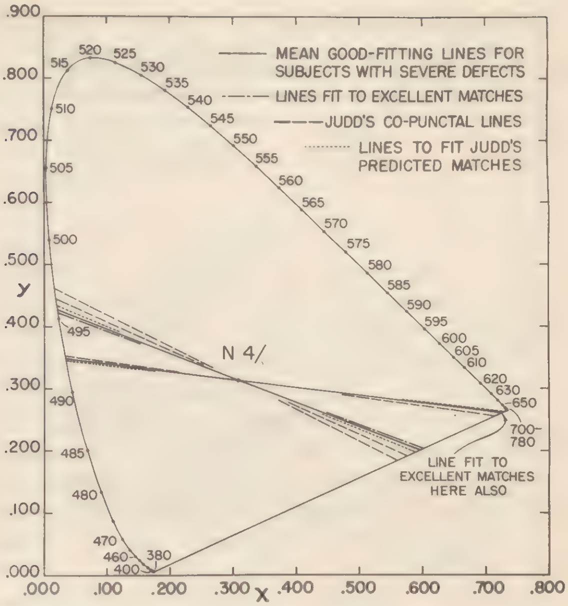

Figure 10. Empirical and theoretical iso-color lines for N 4/ computed according to several techniques.

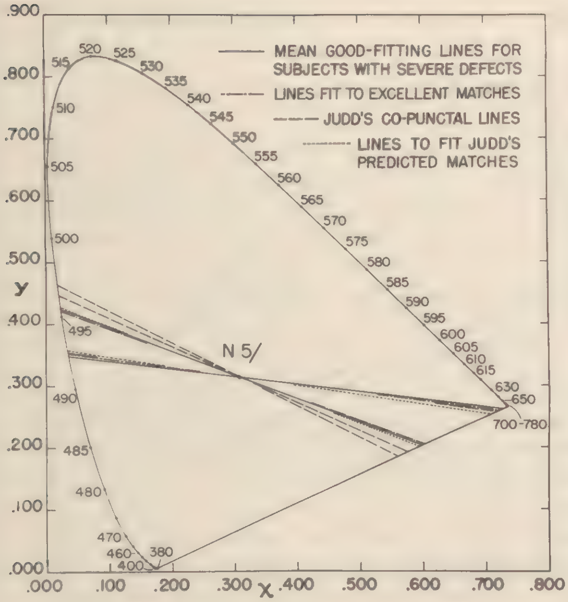

Figure 11. Empirical and theoretical iso-color lines for N 5/ computed according to several techniques.

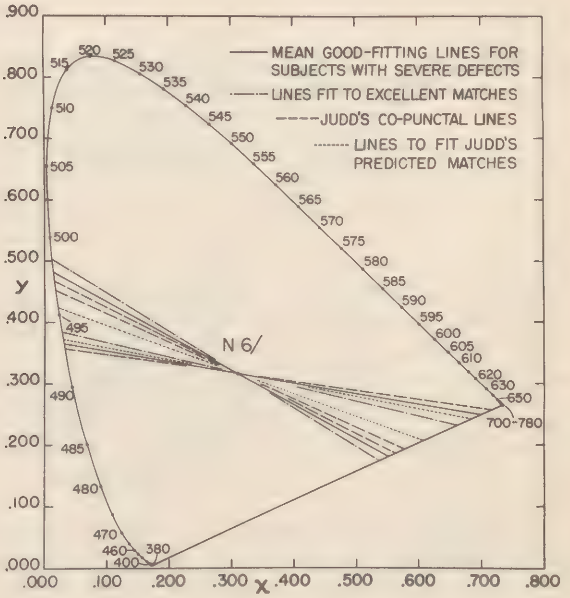

Figure 12. Empirical and theoretical iso-color lines for N 6/ computed according to several techniques.

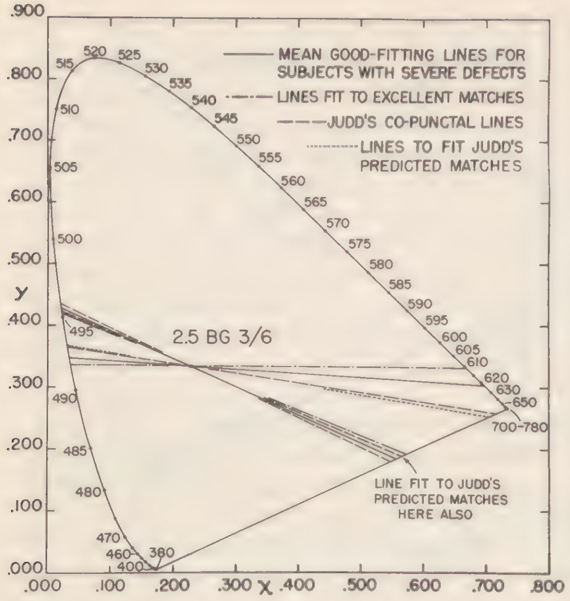

Figure 13. Empirical and theoretical iso-color lines for 2.5 BG 3/6 computed according to several techniques.

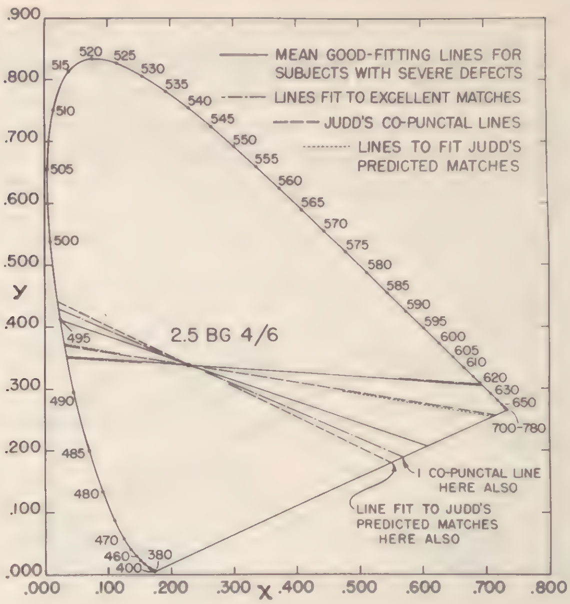

Figure 14. Empirical and theoretical iso-color lines for 2.5 BG 4/6 computed according to several techniques.

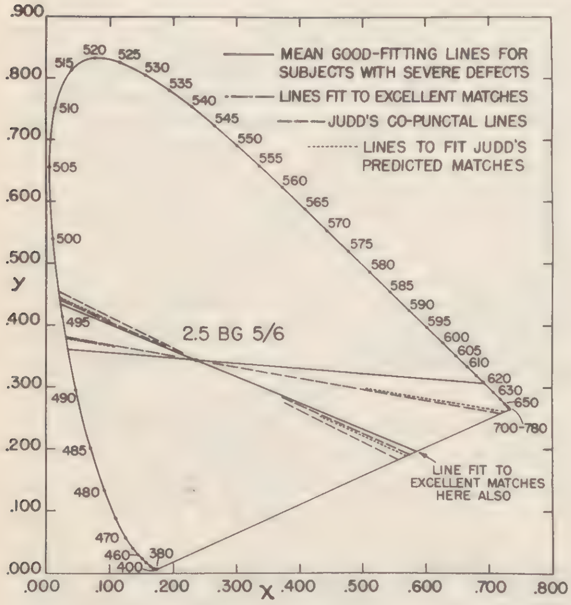

Figure 15. Empirical and theoretical iso-color lines for 2.5 BG 5/6 computed according to several techniques.

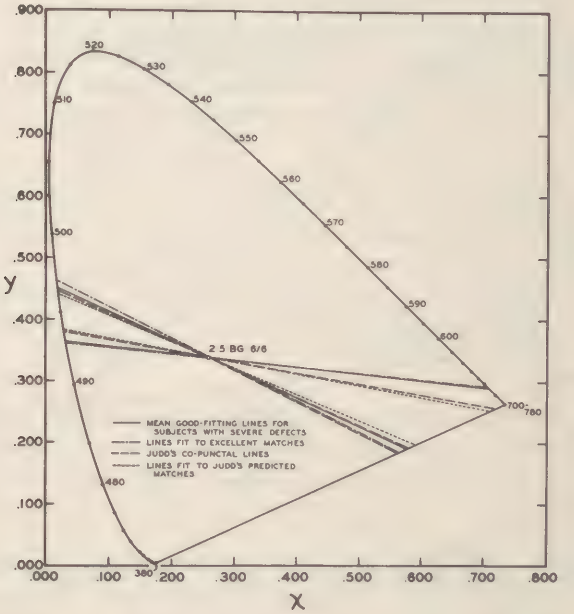

Figure 16. Empirical and theoretical iso-color lines for 2.5 BG 6/6 computed according to several techniques.

illustrated by this example: For a match with 2.5 BG 3/6, Judd's equations would predict that 2.5 R 4/2 (from our selection of Munsell hues at chroma /2) should provide the best match. Actually, Figure 6 shows that no protan ever selected 2.5 R as a match for any BG. Other discrepancies of this magnitude are common.

C. Relative Brightness of Matches

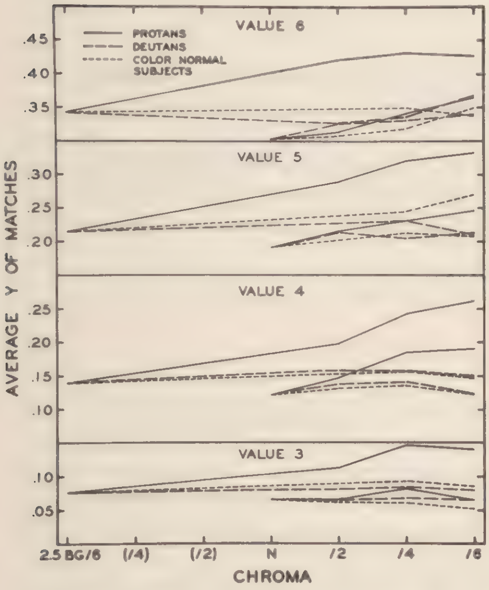

Figure 17. Average Y values (brightnesses) of the matches made to the neutral and blue-green standards by each group of subjects. Standards occur above the abscissa notations 2.5 BG /6 and N; average Y values occur above the abscissa notations /2, /4, and /6.

The distribution of average Y-values for all matches by each subject show several important relationships. There is no difference between the average Y of matches made by protans with severe and mild defects, nor between those for deutans with mild and severe defects. The deutan and normal distributions are similar, while that for the protans is displaced toward higher values. The tendency of protans to select matches at higher brightnesses than the standards is indicative of their lowered sensitivity to red, and is more pronounced for matches with blue-green.

The data were also analysed to discover whether the brightness of the matching colors was constant at all chroma levels. In Figure 17 the average Y for matches at each chroma and with each standard is plotted against a linear chroma scale. It can be seen that the Y values for matches by deutans and normals are nearly constant at all chroma levels, while for protans there is an increase with chromas farther from the standard. This increase is slight for matches with neutral, but very great for matches with blue-green. The rate of increase appears to be constant, however, and the same for both colors of the standards.

V. DISCUSSION

Several important limitations of this study should be emphasized. These are:

1. We provided the subject with discrete steps, and not continuous variations, of color. Our arrays of Munsell hues were as complete as we could get, but it was apparent nonetheless that small variations in hue, or in brightness, frequently made it difficult for subjects to select matches which completely satisfied them.

2. The Munsell hue series covers only the middle section of the ICI diagram. As is apparent from Figure 3, Munsell hues are not available in very high saturations.

3. We explored only a few of the iso-color lines in the ICI diagram. We had the practical choice of establishing a few points with considerable precision and with a large number of subjects, or of sampling more widely with fewer subjects and somewhat less precision. We selected the former alternative.

4. We have been forced to extrapolate our iso-color lines far beyond the empirical data. We recognize full well the danger of such extrapolation and have drawn the data in this way to emphasize the trends.

VI. SUMMARY

In this investigation we have explored some of the iso-color lines of color-deficient vision with Munsell hues. The results show a consistency far exceeding our expectations and justify these conclusions:

1. Color-deficient subjects of the protan variety select matches which differ clearly from the matches selected by deutans.

2. Color-deficient subjects with mild defects tend to select the same matches as do those with severe defects, but the former show more variability.

3. Iso-color lines for deutans are in general agreement with available predictions from spectral data. Iso-color lines for matches with neutral standards by protan subjects also agree with available predictions. But lines for matches with blue-green standards by protans diverge markedly from predictions.

VII. REFERENCES

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2. Judd, D. B. Standard response functions for protanopic and deuteranopic vision. J. Res. Nat'l. Bur. Stand., 1944, 33, 407-437.

3. Judd, D. B. Color perceptions of deuteranopic and protanopic observers. J. Res. Nat'l. Bur. Stand., 1948, 41, 247-271.

4. Pitt, F. H. G. Characteristics of dichromatic vision. Med. Res. Coun. Spec. Rep. Ser. No. 200. 1935. 58 pp.

Discussion:

Dr. Sloan inquired as to how Dr. Chapanis classified mild and severe deutans and protans.

Dr. Chapanis stated that subjects were classified by a battery of measures and that severe defect was considered to exist only when the measures were constant in indicating severe defect.

Mr. Middleton expressed surprise that Dr. Chapanis did not have trouble obtaining responses from protans due to the fact that protans observe brightness differences as well as hue differences between the pairs to be compared.

REPORT OF THE WORKING GROUP
on
A COLOR CODE FOR COMPRESSED GAS CYLINDERS
and
PIPE LINES

Deane B. Judd, Chairman

The report of the working group on color coding takes the form of a paper entitled "The Selection of Colors for Coding" and a series of recommendations concerning difficulties with the present code and suggestions for a modified code. The paper and the recommendations are presented below:

The Selection of Colors for Coding

A criticism of MIL-STD-101, Color Code for Compressed Gas Cylinders and Pipelines

Introduction

The need for quick identification of the contents of gas cylinders and pipelines scarcely needs emphasis. In an emergency, a person with no technical training may have to take quick action relative to a certain pipeline or compressed gas cylinder. He may not have time to find and decipher the possibly unfamiliar name of the contents, but he can be told, "Shut off the valve in the blue pipe!" or "Bring the red cylinder!" and if his color vision is normal, his response to the emergency order will be prompt and have a minimum chance of error.

Partly on this account and partly for less urgent routine use, there has been issued a military standard (MIL-STD-101, 14 July, 1949) Color Code for Compressed Gas Cylinders and Pipelines, identifying six colors (Yellow, Brown, Blue, Green, Gray, Red) to be used as warning colors, and four colors (Black, White, Orange, Tan) for general uses as specified. The identification of the colors is by Federal Specification TT-C-595, Colors for Ready-Mixed Paint, so that there is little doubt as to the exact color intended. The choice of the colors is such that for an observer having normal color vision, the colors are readily distinguished by name. Unfortunately, however, the colors selected will be confused by persons whose color vision is red-green defective. It is the purpose of the present report to present the evidence that confusions will result from the use of MIL-STD-101 and to present two selections of colors which could be substituted for the colors designated in MIL-STD-101.

Color Perceptions of Protanopic and Deuteranopic Observers

A considerable number (about one per cent) of the healthy male population possess protanopic vision and on this account, confuse red and bluish green. About an equal number possess deuteranopic vision and on this account, confuse purplish red with green. And there are appreciable numbers of the male population who make these distinctions less readily than observers having normal color vision (Protanomalous 1%, deuteranomalous, 5%). Protanopes and deuteranopes can make color distinctions of but two sorts, light-dark, and yellow-blue, unlike observers with normal color vision who can make in addition red-green distinctions. It is possible, therefore, to analyze the color perceptions of protanopes and deuteranopes by plotting points on a two-dimensional diagram whereas normal color perceptions require for their representation a space diagram (the so-called color solid). The two-dimensional diagram to be used in the present analysis is formed by plotting Munsell value against Munsell chroma, plus for yellow (5Y) and minus for blue (5PB). The deuteranopic match for any

color (X, Y, Z) is found among the colors of Munsell hue 5Y or 5PB and the renotation of the latter is plotted on the two-dimensional diagram as an indication of the deuteranopic perception of color (X, Y, Z) by methods outlined by Judd (J. Research NBS 41, 247; 1947; RP1922) and the protanopic match is similarly plotted. The scales (Munsell value and chroma) of this diagram perceptually are closely uniform so that the degree to which two colors are perceived by the red-green confuser to differ is indicated closely by the distance that separates the points representing them on this diagram. When this distance is comparatively small, the likelihood of the red-green confuser failing to distinguish the two colors is correspondingly great.

A further advantage of this particular two-dimensional diagram for considering the selection of colors for coding rests on the view, shown in RP1922 to be highly probable, that the color perceptions of protanopes and deuteranopes are confined to the hues, yellow (Munsell 5Y) and blue (Munsell 5PB). This view receives its major support from evidence supplied by cases of unilateral colorblindness, persons having one eye partially colorblind, the other eye with color vision normal or nearly so. By this view, anyone having normal color vision can gain an immediate comprehension of what the protanope or deuteranope has to go on when he has to distinguish between the members of any group of colors chosen for color coding. The person with normal color vision has merely to look at the color of Munsell hue 5Y or 5PB confused by the protanope or deuteranope with the coding color in question to see exactly what the protanope or deuteranope in question presumably sees on looking at the coding color.

No special attention need be given protans and deutans of the anomalous trichromatic types (Protanomalous and deuteranomalous). If a group of colors readily distinguishable by name by dichromatic red-green confusers can be found, it is obvious that observers who have some red-green vision to help them will be able still more readily to distinguish colors of the same group by name.

Measurement of the Colors Specified in MIL-STD-101

Two sets of samples of the 10 colors (Yellow, Brown, Blue, Green, Gray, Red, Black, White, Orange and Tan) specified in MIL-STD-101 by reference to Federal Specification TT-C-595 have been measured by means of General Electric recording spectrophotometers with flux reflected near the angle of mirror reflection excluded from the measurement. One set was selected from the master standards for TT-C-595 and was measured at the National Bureau of Standards; the other set was taken from a copy of Federal Specification TT-C-595 purchased from the Government Printing Office and was measured at the National Research Council of Canada in Ottawa. The measurements indicated that the samples of these two sets had colors differing by amounts that are spectrophotometrically significant, and subsequent visual comparison corroborated the conclusion that there are small but easily discernible differences between the two sets of samples. These small differences are of no consequence compared to the large differences between the individual coding colors so that it does not matter for our purposes which set of results is used.

Table 1 gives the tristimulus values (X, Y, Z) and chromaticity coordinates (x, y) of these 10 color samples for standard source C (daylight) based on the spectrophotometric measurements made at the National Bureau of Standards. It also gives similar data for four (4) additional color samples to be discussed later. For all fourteen (14) samples there are also given the protanopic (W_p) and deuteranopic (W_d) chromaticity coordinates, the protanopic reflectance $(W/W_{MgO})_p$ defined in RP1922 (equations 2d and 2p, page 256), and the Munsell protanopic and deuteranopic renotations derived from them by graphical interpolation of the data given in Table 6 of RP1922.

TABLE 1. Tristimulus values, chromaticity coordinates, dichromatic chromaticity coordinates, protanopic reflectance, and dichromatic renotations of the 10 colors specified in MIL-STD-101 and of the 5 suggested substitutes, (Source C).

TT-C -595 No.	Name	Tristimulus Values			Chromaticity Coordinates		Dichromatic Chromaticity Coordinates		Prot-anopic Reflec-tance	Dichromatic Renotations Prot.	Munsell (RP1922) Duet.
		X	Y	Z	x	y	W_d	W_p	$.9733W_p$		
					(Colors specified by MIL-STD-101)						
1105	Red	.1288	.0690	.0185	.5955	.3190	.789	.664	.0355	Y 2.2/2.6	Y 3.1/4.9
1210*	Orange	.3483	.2261	.0176	.5883	.3819	.928	.894	.1449	Y 4.4/8.3	Y 5.3/10.
1310*	Yellow	.4802	.4421	.0239	.5075	.4672	.949	.941	.3721	Y 6.6/13	Y 7.1/14.
1445	Green	.0477	.0874	.0410	.2710	.4964	.681	.711	.0983	Y 3.6/4.1	Y 3.5/3.5
1520	Blue	.0803	.0825	.2547	.1924	.1976	.245	.284	.0982	PB 3.6/7.8	PB 3.4/7.6
1625*	Gray	.1572	.1654	.2010	.3002	.3159	.451	.452	.1682	PB 4.7/0.2	PB 4.6/0.2
1710	Brown	.0652	.0588	.0387	.4005	.3614	.603	.582	.0524	Y 2.7/1.8	Y 2.8/2.1
1755*	White	.7153	.7350	.7899	.3193	.3281	.482	.487	.7297	Y 8.7/0.6	Y 8.8/0.6
1770*	Black	.0022	.0024	.0047	.2349	.2582	.338	.373	.0027	PB 0.3/0.1	PB 0.2/0.1
3320	Tan	.2592	.2585	.1222	.4051	.4040	.679	.667	.2379	Y 5.4/4.4	Y 5.6/4.6
					(New Colors proposed by the Armed Forces-NRC Vision Committee)						
1110	Red	.1867	.0998	.0258	.5979	.3196	.795	.670	.0509	Y 2.6/2.9	Y 3.7/5.3
1745	Buff	.4822	.4844	.2736	.3888	.3906	.639	.629	.4517	Y 7.1/4.5	Y 7.4/4.7
2715	Purple	.1867	.1446	.2964	.2967	.2306	.328	.322	.1370	PB 4.2/6.5	PB 4.4/5.1
10B 7/6	Blue	.4150	.4576	.7761	.2517	.2776	.371	.396	.4958	PB 7.4/4.9	PB 7.2/5.2

*These colors are considered to be satisfactory as elements of a nine-color system.

Table 2 gives similar data for standard source A (incandescent-lamp light) as the illuminant. For estimating judgments by a red-green confuser adapted to incandescent-lamp light, the protanopic and deuteranopic chromaticity coordinates have been adjusted by the factors (1.154 for W_p, 3.327 for K) required to keep the chromaticity coordinates of non-selective specimens invariant. This is based on the assumption that an observer adapted to incandescent-lamp light will perceive spectrally nonselective specimens as grays. Thus, for incandescent-lamp light, instead of $w_p = W_p/W_p + K)$, we have used:

$$w'_p = 1.146W_p/(1.146W_p + 3.327K)\text{; and instead of } w_d = w_d/W_d + K),$$

we have used $w'_d = W_d/(W_d + 3.327K)$.

Unsuitability of the Colors Chosen for MIL-STD-101

Figure 1 shows the protanopic Munsell renotations (circles) and the deuteranopic Munsell renotations (squares) plotted on the value vs. chroma diagram for daylight illumination. The four non-warning colors (White, Black, Orange, Tan) are indicated on this plot by small open circles and squares to distinguish them from the more important warning colors plotted as solid circles and squares. It will be noted that the protanopic observer perceives the red and orange specimens as considerably darker and weaker colors (olive browns) than the deuteranopic observer. It is also evident that the brown sample should be perceived by the protanopic observer as not much different from the red, and that the deuteranopic observer should perceive the green sample as not much different from the red. These brown, green, and red specimens will obviously be confused by protans and deutans.

Proposed Revision of the Color Code

A revised color code has been developed in order to eliminate the danger of color confusions by red-green confusers. The ideal color code consists of only four colors, black (1770) white (1755) yellow (1310) and blue (10B7/6). These colors are equally distinctive and equally recognizable by name to red-green confusers and persons of normal color vision alike. Restriction of the colors used for coding to these four colors will still not provide positive protection against errors under all conditions; that is, if the illumination is extremely low or quite different in spectral character from daylight, observers of all types may make mistakes. Addition of other colors increases this danger of confusion in the sense that completely reliable identification by name requires higher illuminations and more restricted departures from the spectral character of daylight. The maximum number of colors that can be safely used under practical conditions for coding is nine (9) and these must be specially chosen with regard for the discriminative limitations of red-green confusers since it is not possible to prevent situations arising in which such observers must make use of the color code.

The color code consisting of nine (9) colors would include as warning colors: red (1110), orange (1210), yellow (1310), blue (10B7/6), purple (2715), and gray (1625); as non-warning colors: white (1755), black (1770), and buff (1745). In Figure 2, this set of nine colors is plotted on the value versus chroma diagram for daylight illumination. The distances between various pairs of colors may be compared in Figures 1 and 2. Note that the nine (9) colors proposed by the Armed Forces-NRC Vision Committee as the maximum number will be satisfactorily differentiated by red-green confusers.

In Figure 3, the same nine (9) colors are shown in terms of incandescent-lamp illumination. The spacing is somewhat changed. The red and orange specimens correspond in lamp-light to lighter, more saturated colors for the red-green confusers than they do in daylight. But it is still true that no two of the nine (9) colors are close duplicates either for protanopic or for deuteranopic vision.

TABLE 2. Tristimulus values, chromaticity coordinates, dichromatic chromaticity coordinates protanopic reflectance, and dichromatic Munsell renotations of the 10 colors specified in MIL-STD-101 and of the 5 suggested substitutes, (Source A).

TT-C -595 No.	Name	Tristimulus Values			Chromaticity Coordinates		Dichromatic Chromaticity Coordinates		Protanopic Reflectance	Dichromatic Renotations Prot.	Munsell (RP1922) Deut.
		X	Y	Z	x	y	w'_d	w'_p	$1.124W_p$		
					(Colors specified by MIL-STD-101)						
1105	Red	.2060	.1014	.0056	.6581	.3240	.845	.730	.0491	Y 2.6/3.7	Y 3.7/6.2
1210*	Orange	.5246	.3042	.0062	.6289	.3637	.937	.906	.1941	Y 5.0/9.4	Y 6.0/12
1310*	Yellow	.6568	.5102	.0099	.5581	.4335	.939	.932	.4409	Y 7.1/14	Y 7.5/14
1445	Green	.0515	.0766	.0159	.3574	.5319	.592	.641	.0922	Y 3.5/3.0	Y 3.2/1.8
1520	Blue	.0552	.0673	.0707	.2918	.3345	.212	.249	.0761	PB 3.2/9.1	PB 2.9/8.4
1625*	Gray	.1721	.1627	.0606	.4353	.4115	.447	.459	.1664	PB 4.6/0.2	PB 4.6/0.4
1710	Brown	.0830	.0650	.0118	.5196	.4067	.623	.618	.0577	Y 2.8/2.4	Y 3.0/2.5
1755*	White	.8168	.7401	.2403	.4545	.4118	.481	.486	.7355	Y 8.8/0.6	Y 8.8/0.6
1770*	Black	.0020	.0022	.0014	.352	.396	.319	.347	.0025	PB 0.2/0.1	PB 0.2/0.1
3320	Tan	.3284	.2785	.0388	.5086	.4313	.683	.674	.2600	Y 5.6/4.6	Y 5.8/4.8
					(New Colors proposed by the Armed Forces-NRC Vision Committee)						
1110	Red	.2980	.1469	.0078	.6582	.3245	.850	.737	.0711	Y 3.1/4.2	Y 4.4/7.0
1745	Buff	.6045	.5162	.0857	.5011	.4279	.644	.636	.4857	Y 7.4/4.8	Y 7.6/4.9
2715	Purple	.2098	.1522	.0843	.4701	.3410	.352	.328	.1335	PB 4.2/6.1	PB 4.5/4.2
10B 7/6	Blue	.4053	.4205	.2348	.3821	.3965	.350	.377	.4595	PB 7.2/6.1	PB 6.9/6.3

*These colors are considered to be satisfactory as elements of a nine-color system.

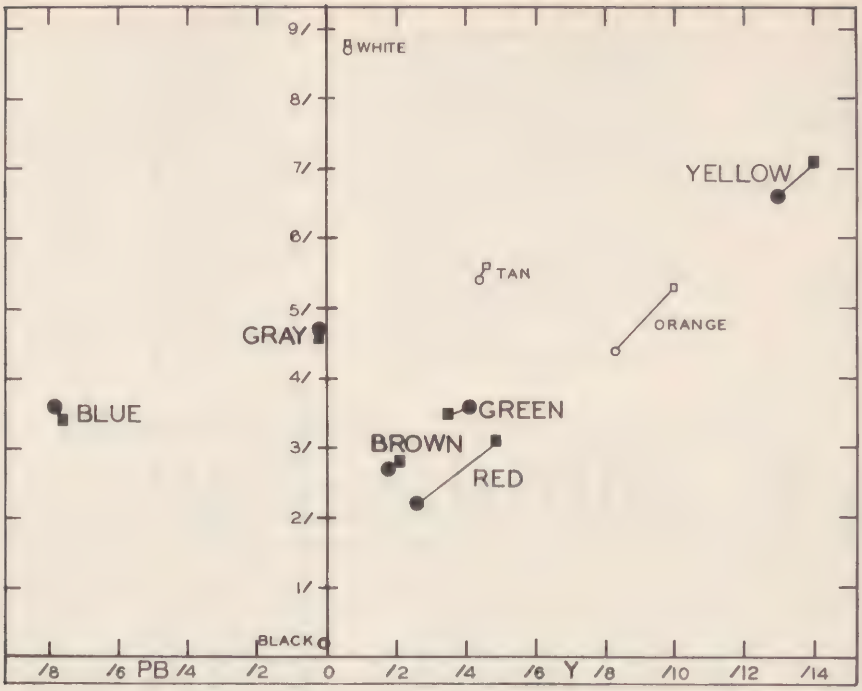

Figure 1. Protanopic and deuteranopic Munsell renotations of the ten colors specified in MIL-STD-101 for color coding for daylight illumination

Legend: | Warning | Non-warning
Prot. ● ○
Deut. ■ □

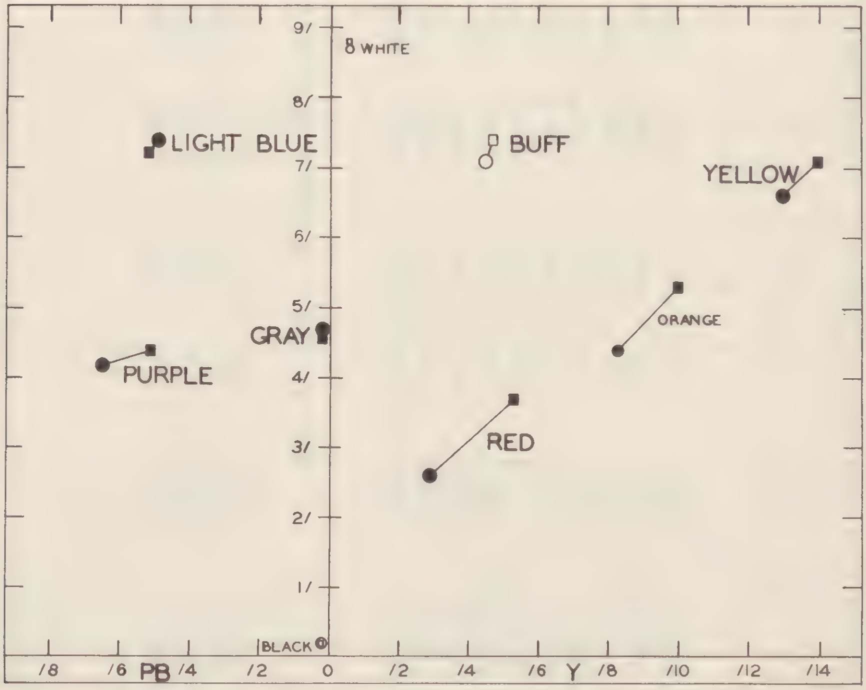

Figure 2. Protanopic and deuteranopic Munsell renotations of the nine colors proposed as the maximum number of safe colors for use in a color code, for daylight illumination

Legend: | Warning | Non-warning
Prot. ● ○
Deut. ■ □

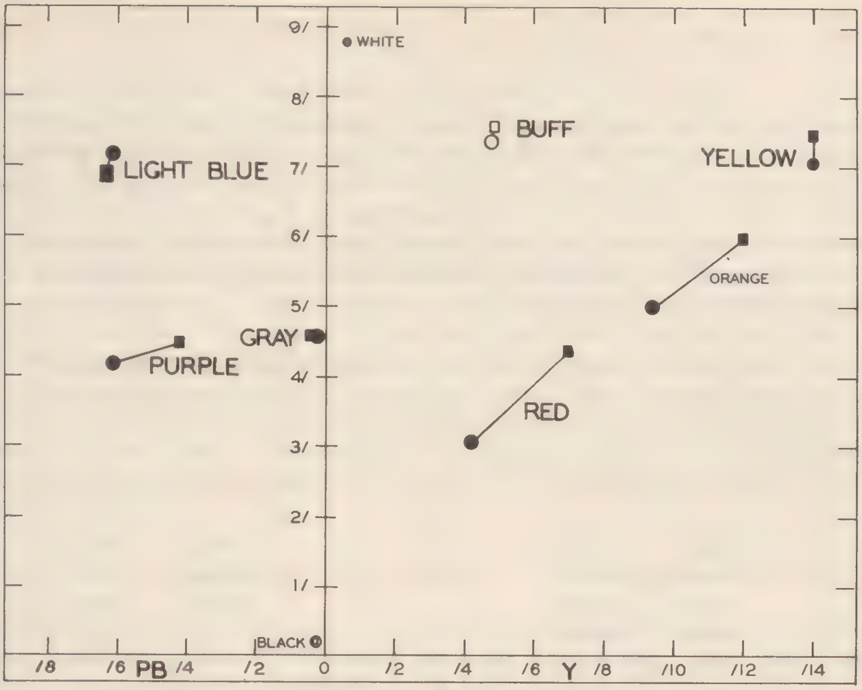

Figure 3. Protanopic and deuteranopic Munsell renotations of the nine colors proposed as the maximum number of safe colors for use in a color code, for incandescent-lamp illumination.

Legend:	Warning	Non-warning
Prot.	●	○
Deut.	■	□

The nine color system was tested with five red-green confusers and it was shown that these people are able to recognize the colors by name as are normal observers.

The nine color code has been shown to be markedly superior to the color code MIL-STD-101. It is recommended that MIL-STD-101 be immediately rescinded and replaced by the nine color code described above. It is emphasized again that the four color code described above would be superior to the nine color code. However, if a four color code will prove unduly restrictive, the nine color code may be adopted with reasonable safety.

Recommendation On a Color Code for Compressed Gas Cylinders and Pipe Lines

The color code for compressed gas cylinders and pipe lines, designated MIL-STD-101, specifies six (6) colors for warning and four (4) colors for general uses as specified. When the subject code was transmitted to the Canadian Defense Department with a view to effecting joint standardization, the code was criticized on the grounds that an appreciable percentage of the healthy male population would confuse colors in the code due to defective color vision. The subject standard was referred to the Armed Forces-NRC Vision Committee for study. A working group was established to consider the adequacy of the color code and to recommend, if necessary, an alternative code.

Analysis of the color code revealed the fact that color confusions must be expected when the code is utilized by from five (5) to eight (8) per cent of the healthy male population. It is recommended that the color code be immediately rescinded since it is possible

to foresee dangerous accidents arising from color confusions by those with defective color vision.

The working group has developed a color code which will not lead to color confusions by those with defective color vision. A four (4) color code is specified which is considered to be the only code which will be maximally free from color confusion by those with normal and defective color vision. Since it is expected that a four-color code will be unduly restrictive, a nine-color code has also been developed. This code represents the maximum number of colors which can be utilized by those with normal and defective color vision with only moderate danger of color confusions.

The nine (9) color code consists of the following colors, identified by name and by number in Federal Specification TT-C-595, Colors for Ready-Mixed Paint (or in Munsell notation):

Warning Colors		Non-Warning Colors	
Red	1110	White	1755
Orange	1210	Black	1770
Yellow	1310	Buff	1745
Blue	10B7/6		
Purple	2715		
Gray	1625		

The basis for criticism of the present standard as well as the considerations which led to the two new proposed codes are discussed in full in an attached report entitled "The Selection of Colors for Coding".

It is recommended that immediate steps be taken by the appropriate officers of the Department of Defense to rescind the prevailing standard and substitute for it either the four (4) color code or the nine (9) color code. Members of the working group of the Vision Committee would be pleased to confer with the appropriate officials of the Department of Defense in order to clarify the criticism of the prevailing standard and the basis for selection of the proposed code.

Submitted by members of the Working Group on A Color Code for Compressed Gas Cylinders and Pipe Lines.

Dr. Deane B. Judd, Chairman
Dr. Alphonse Chapanis
Lt. Comdr. Dean Farnsworth
Mr. W. E. K. Middleton
Dr. Louise Sloan
Dr. H. W. Rose

Discussion:

Dr. Neuberger stated that his color vision is normal but that he felt unable to be certain of the difference between the yellow and buff colors selected by the working group. Dr. Neuberger emphasized the greater difficulty in discriminating between these colors after the yellow became dirtied.

Dr. Judd agreed with Dr. Neuberger that the buff and yellow are not optimally different. Dr. Judd emphasized that only four colors may be selected which do not run the risk of color confusion. Unfortunately, the military departments feel that they need more colors than this for color coding and for this reason, the best possible additional colors have been determined.

Dr. Chapanis emphasized the distinction between the warning and the non-warning colors in the proposed color code. Yellow is a warning color and buff a non-warning color. The use of the two colors could minimize the possibilities of confusions between these two colors.

Mr. Breckenridge noted that he found the orange and red samples difficult to discriminate.

Mr. Middleton emphasized that only four colors are entirely safe but that more colors are considered necessary by the military authorities. Mr. Middleton commented further that he did not believe anyone would actually mistake red and orange when seen at large subtense. It is true that from Mr. Breckenridge's seat in the auditorium the red and orange samples subtend small angles and therefore, color discrimination is more difficult.

REPORT OF THE WORKING GROUP ON SUNGLASSES

John L. Matthews, Chairman

The present report represents answers prepared by the working group in response to a series of questions submitted by Col. Albert E. Dennis of the Office of the Quartermaster General, Department of the Army. The initial portion of the report takes the form of a series of brief answers to the questions concerning issue of sunglasses.

Question 1: Is there a physiological need for sunglasses by the average soldier not subject to extreme glare but who may on occasion and for short duration be subjected to moderate glare such as reflection from highways and buildings, late afternoon sun, midsummer glare, etc. ?

Answer 1: No.

Question 2: If so, is this need due to possible retinal or oculomuscular damage, or is it based solely on a significant decrease in comfort or visual efficiency when no glasses are worn?

Answer 2: There is no evidence that there is retinal or "oculomuscular damage" from light of even high brightness.

Question 3: Is the amount and duration of impairment of dark adaptation due to glare sufficient to require the issue of sunglasses to troops not actually engaged in night combat or exposed to other situations where dark adaptation is necessary for maximum individual security?

Answer 3: No.

Question 4: Apart from any physiological need for the item which may exist, is there a psychological requirement evidenced by subjective feeling of need for sunglasses under certain conditions?

Answer 4: It is recognized that there are individuals who are especially glare-sensitive. It should be the responsibility of the medical department to control issue of sunglasses to such individuals. It is also recognized that there are tasks and assignments which expose the individual of high glare tolerance to such extreme brightnesses as to necessitate the issue of sunglasses to those so assigned. In addition, possibly because of extensive advertising, military personnel in general feel the need for sunglasses even though there is no physiological need for their use. It is the opinion of members of the working group that fulfilling this psychological need for sunglasses is unnecessary and would prove unduly expensive.

Question 5: Is an accustomization and indoctrination program feasible for those men and in those areas where it is found that sunglasses are not physiologically needful, in order to offset the subjective feeling of need for the item if such exists?

Answer 5: No.

Question 6: What is the role of accustomization in decreasing the effect of glare on visual efficiency or comfort?

Answer 6: The average individual develops a greater tolerance to high brightness on continued exposure.

Question 7: It is known that the degree of tolerance to light varies with the individual, but it is suspected that there is a norm for tolerance for varying light intensities. If so, is it possible to give statistical information based on normative data as to the probable number of troops who would need sunglasses under varying conditions of light intensity?

Answer 7: The degree of tolerance varies with the individual, but norms of tolerance to varying light intensities have never been determined. It is therefore impossible to give the statistical information requested.

Question 8: Are there any special problems relating to need for, or design of, sunglasses posed by solar radiation in dust and/or moisture-free environments such as high mountain tops?

Answer 8: The greater intensities of radiant energy in such environments demand the issue of protective glasses to troops who might operate therein. Such lenses should be sufficiently large to eliminate the greater portion of reflected radiation.

The members of the working group realize that these answers are not those specifically desired by the Quartermaster General, i. e., those from which requirement formulas might be precisely set. We believe the best that can be done is to state that troops assigned to environments of known excessive brightnesses (mountain and ski) should rate 100% issue; and other troops an issue based on determined need.

It is possible that the Quartermaster may be more concerned with long-range procurement requirements for large masses of men rather than specific allocations to smaller units. Assuming mobilization of millions of men and a world-wide geographic distribution of troops similar to that of World War II, we believe it possible to hazard a guess as to the percentage of the total military population whose efficiency might be improved by the issue of sunglasses. 20% issue will probably approximate this requirement. More precise allocations to units must be based on issue experience with special populations under special conditions.

John L. Matthews, Chairman
Hedwig S. Kuhn
Dean Farnsworth
Louise Sloan Rowland

Discussion:

Dr. Chapanis stated that he was unhappy about the idea that the psychological "need" for sunglasses should be ignored in considering their issue. Dr. Chapanis stated that in his opinion a psychological need might at least be as important as a non-physiological need.

Col. Byrnes commented that he believed it was the concensus of opinion of the Vision Committee that the psychological "need" for sunglasses is an excessively expensive need to satisfy.

The Chairman asked for the concensus of the Vision Committee as to the acceptability of the report of the working group for transmission to the Army as a formal reply to the questions raised by the Quartermaster General. The report was approved by the Vision Committee in the above form.

SUMMARY OF THE REPORT OF THE WORKING GROUP ON THE MANUAL OF INSTRUCTIONS FOR THE CLINICAL TESTING OF VISUAL ACUITY

Richard G. Scobee, Chairman

The Vision Committee recently prepared standard charts for use in the armed services in the clinical testing of visual acuity at distance and at near. These charts are presented in the Minutes and Proceedings of the 27th meeting of the Committee, November 10-11, 1950. The charts were forwarded to the Chairman of the Armed Services Medical Materiel Specification Committee for adoption as standard charts within the armed services for clinical testing of visual acuity. Recently, a request was received from the Chairman of the Specification Committee indicating the need for a manual to be used with the standard acuity tests. The present working group was set up to prepare a manual for this purpose.

The working group has modified the "Manual of Instructions for Testing Visual Acuity" which was published by the Vision Committee in October, 1947. Editorial changes were made in the manual to make it appropriate for use merely in clinical testing of acuity. The earlier manual had been used in administering acuity tests for selection and classification as well as for clinical refraction purposes.

The revised manual is being lithoprinted and copies of it will be circulated to members of the Vision Committee within a few months.

Discussion:

There was some question from the floor as to why the manual was necessary. It was pointed out that a trained ophthalmologist does not need a manual to use in testing visual acuity and would not use one if he had it.

Col. Byrnes expressed his opinion that the manual is needed since in many cases relatively untrained technicians may be called upon to give acuity tests and that the manual would be useful to them in order to standardize the conditions of the test.

The Chairman asked the concensus of Vision Committee opinion concerning the desirability of preparing a manual and it was the sense of the group that the manual should be forwarded to the Chairman of the Specification Committee as requested.

REPORT OF THE WORKING GROUP ON NIGHT VISION TRAINING

William S. Verplanck, Chairman

Introduction

As we view it, night-vision training is perceptual training. It must include three essential features: (1) it must familiarize the trainee with pertinent facts on how to use his eyes at night, (2) it must present to him a wide variety of objects representative of those he must learn to see under low levels of illumination, and (3) it must give him opportunity for effective practice in the visual motor and perceptual skills involved. All three features are indispensable.

The evaluation of night-vision training devices involves, therefore, considerably more than a simple assessment of the technical or mechanical advantages of particular synthetic training devices; their cost, ease of maintenance, etc. It involves more than a simple determination of the success with which a given apparatus demonstrates particular aspects of night vision. In order to reach an evaluation, it is necessary to consider a complete program of night-vision training -- to judge each instrument as a part of that program, and to consider each device or technique in relation to whatever others might be required to implement the program as a whole. The Working Group has, therefore, directed its primary attention to the consideration of an over-all program, designed to meet the requirements stated above, with specific suggestions on devices that might be used to implement it. These suggestions in most respects proceed along lines already tested by experience; more recently, they have been independently proposed by members of the staff of the School of Aviation Medicine.

The program we outline is in no sense unique. In content and general approach it closely approximates the night-vision training programs that were developed and used during the recent war. It includes concrete recommendations for an elementary indoctrination period: lecture, demonstrations, and practice, lasting one-and-a-half to two hours, to be given to men relatively early in their training, and tentative suggestions for advanced training specifically related to the visual tasks that may be encountered in the various branches of the service.

Basic Indoctrination

Basic indoctrination in night vision should be administered to all aircrew members during the period of basic training. It should be a simple and straightforward presentation of elementary facts, convincingly and interestingly demonstrated, with opportunity for perceptual practice. Insofar as is possible, the demonstrations should lead the trainees to discover the facts for themselves. The atmosphere of a formal lecture should be avoided. The demonstrator should forego physiological and technical language.

Training at this stage will require about two hours. The room in which the training is conducted should be light-tight. It should be equipped with an efficient ventilating system. It should provide, at one end, a diffusely reflecting white screen subtending, at the eyes of each trainee, a visual angle of at least 50° in the horizontal plane and 30° in the vertical. To accommodate training groups of up to fifteen men it would need to be about 18 by 24 feet with a 10-foot ceiling. Details for the construction of a suitable room may be found in the RCAF Night Vision Training Manual.

The size of the area to be viewed, the screen, is one of several factors that dictate that not more than fifteen men be trained simultaneously. All the men in a group of this size can sit at nearly the same angle and distance from the screen in a room of the size suggested above. This ensures that the targets will be approximately the same size for all, as they must be. At the same time, the small group makes it possible for the instructor to bring each member of the group into direct participation; he may ask each man individually what he sees, and in this way be certain that he will be able to report to the medical department, for ophthalmological examination, all men who fail to see the illuminated screen and its targets (vide infra). When large groups of men are trained together, it is possible for individuals to go to sleep and avoid training, to sit silent and avoid practice, and even to fail to see anything whatever, and all this without the knowledge of the instructor. The instructor, in brief, must be able to control individually the participation of each member of the group being trained.

At the same time, a lower limit on the number of men in a class suggests itself. When fewer than six men are trained together, it is difficult for the instructor to establish the useful competitive atmosphere that strongly encourages individual participation and facilitates practice.

The training period should begin in a well-illuminated room. The general illumination should be at least 20 foot-candles and preferably greater in the region occupied by the trainees and on the screen they are facing. After brief introductory remarks, the lights should be turned off. At the same time a scene should be projected upon the screen at a level of illumination approximating that of the starlit sky.

As dark adaptation proceeds, the instructor should take every advantage of the gradually increasing sensitivity of the eyes of his trainees to bring out one by one the facts of seeing in the dark. He should be sure to include clear and convincing demonstrations of each of the following phenomena:

a. Dark adaptation and the use of red light and goggles.
b. Off-center vision.
c. Loss of visual acuity.
d. Loss of contrast acuity.
e. Loss of color vision
f. Methods of scanning and their effectiveness.
g. Glare.
h. General light adaptation of the retina.
i. Easy fatigability of a given retinal area.
j. Autokinesis or other illusory movement (with special reference to the oculogyric illusion).

In general, emphasis should be placed on what <u>can</u> be seen by the dark adapted eye rather than on the difficulty of seeing. These basic points of emphasis may be supplemented by consulting such standard manuals on night vision as the RCAF Training Manual, or the Naval Aviation Training Manual.

It should be noted that no mention has been made of <u>instructional</u> films on night vision. It is the consensus of the Working Group that such films should not be used. Although they may serve the function of familiarizing the trainee with certain facts about seeing at night, they may lead to nothing except verbal learning and may actually interfere with practice. They are also conducive to lazy teaching by the instructor.

The material to be used for projection should be at least as adequate and varied as that provided in the RCAF trainer, or similar projection apparatus. In spite of certain shortcomings we believe that the RCAF Night Vision Trainer (which will be discussed below

together with suggestions for its improvement) is the most nearly adequate of the devices produced to date for instruction and practice in the fundamentals of night vision. If the Air Force wishes to get a training program under way in minimum time, it will do well to procure copies of this device.*

The proposed improvements in or developments of the RCAF trainer are chiefly of a mechanical sort. The projected "new" trainer would be used under the same circumstances, in the same sort of room, and so on, and it would not require the personnel responsible for the actual training of airmen to alter their instructional approach. That is to say, an improved "new" device could be substituted, suddenly or gradually, for the currently available RCAF traner without any disruption in training. Let us indicate the lines such development should take:

The slide projector incorporated in the RCAF trainer presents a smaller field than is desirable. The use of a wide-angle lens in the projector should overcome this difficulty. The type of realistic material available on slides might then be presented in broad panorama as in the case of the RCAF instructional silhouette projector.

An increase in the size of the projector field would, of course, render ineffective most of the slides incorporated in the RCAF series as not standardized (incorrect target-sizes, etc.). Since the appearance of new types of planes, etc., has already rendered part of the RCAF slide material obsolete, new slides must be developed in any event.

When a broad field of view has been obtained, and when a projector has been designed to operate so as to produce screen brightnesses ranging continuously from dimmest starlight to low day levels, it should be possible to employ a single projector to fulfill the functions of both types of projectors incorporated in the present RCAF trainer. Furthermore, if the projector has sufficient depth of focus, one slide could project a landscape while others, inserted simultaneously, might introduce moving ground targets, aircraft, etc. Such a device should prove simpler and less cumbersome than the present trainer.

The stylized landscape silhouette of the RCAF trainer has many points that recommend it as an instructional aid. It provides items of graded difficulty and presents calculated ambiguities that may be clarified by adequate observation. Items are clearly separated along the horizon so that attention may be directed easily to this or that feature without confusion. On the other hand, the targets silhouetted are highly stylized, and are presented at maximum contrast. They lack realism and variety, and consequently do not provide for practice in seeing and identifying targets as they are actually observed.

It is suggested that objects of varying contrast be introduced into the RCAF trainer. If the slide projector described above should be perfected, the projection of a series of carefully selected actual scenes would become possible. These scenes would add the virtue of realism to those of the silhouette outlined above. Color slides could be employed, so that the emergence of color and color contrast at moonlight and low daylight brightnesses could be demonstrated with the same scene, and so that the misleading perceptual effects observed at twilight might be incorporated into the training.

It would be necessary, of course, to test any such newly developed landscape for "teachability," to make sure that the effectiveness of the demonstration was actually improved, and that the new features did not, in fact, lessen the impact of the demonstration as a whole.

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*Numerous versions of this trainer have been produced. The best model to take as a prototype would probably be that at the RCAF School of Aviation Medicine, Toronto, Ontario.

A good deal of careful thought will be necessary in the selection of material for projection at all levels of training. It is almost a requirement, too, that a steady succession of new trainees be available during the developmental period in order that new materials may be inserted into the general program only when they have proved their effectiveness as demonstration aids.

After the basic demonstrations are over, the final minutes of the class period should be used to show by means of slides or motion pictures, further varieties of realistic and appropriate material. These should be in color, wherever possible, so that, when they are projected at several low levels of illumination, a variety of visual conditions, from starlight and below up through moonlight and twilight, can be simulated.

No matter what type of material is employed, it should never be suggestive of a test of night vision, nor should it offer a basis of any kind for scoring. Trainees who seem to perform poorly in the training period or who complain of being unable to see at night must, however, be identified in the training situation, and it is essential that they be reported and referred to the Flight Surgeon, who may recommend ophthalmological examination. The training procedure naturally and directly enables the instructor to find such men, and this is an indispensable feature of it. Nonetheless, it cannot and should not be thought of as a test in the strict sense of the term. Tests for the diagnosis of night blindness can be effectively given only in laboratories, under highly controlled conditions, and by technically qualified personnel. It is suggested that suspect individuals be referred by the Flight Surgeon for such examination to centers where visual research is being done, such as the School of Aviation Medicine, or the Aero-Medical Laboratory.

Night-vision training should be carried out under the direction of an aviation physiologist or psychophysiologist, who should be held fully responsible for its excellence. Instructors should be familiar not only with the equipment and facts of night vision, but also with proper instructional technique. To obtain this they should undergo a period of practice-instruction, in the course of which they should demonstrate their ability to interest, and capably instruct, trainees. The instructors should furthermore be interested in night-vision training. They should be what one describes as "good teachers," capable of establishing rapport with a class easily.

Evaluation of Night-Vision Training

Some of those who work with specialized training procedures tend to become enthusiasitic about their work, and perhaps unrealistic in describing its utility and in urging the adoption of broader and longer programs. This necessarily provokes a healthy skepticism and suggests that some evaluation should be made of every training procedure. In the present case, there are no evaluative data at hand. There are opinions; those who have dealt with a broad variety of night visual problems have reached the conclusion that training may provide the answer to many of them. There are, too, many testimonials from operational personnel. But night-vision training is not Hadacol, and scientists are interested in more adequate proofs of the value of a procedure before recommending that an extensive training program be based upon it.

Although it is impractical, if not impossible, to attempt to validate the relative benefits of night-vision training and operational performances, something might be done to answer the questions of those who doubt that night-visual training may enable a man at some critical moment to extract more useful information with his eyes than he might have obtained without training.

No one has argued that an airman should not know about dark adaptation, the purpose of red illumination, the existence of central scotomata in dim light, and so on. All agree

that training, as currently contemplated, presents the trainee with numerous facts and seeks to impart elementary practice in numerous skills, any one of which might conceivably make "all the difference" for some man at some time, upon whom other men must depend. The question is the relative value of night vision as opposed to various alternative expenditures of time and effort in the airman's training. How substantial are the benefits derivable from training, and how much time in training is required to achieve them?

It should be possible to obtain suggestive answers to these questions by setting up a series of realistic visual problems, using projected slides or films. From these scenes trained and untrained men might be asked to report specific items of information. Some preliminary work would need to be done in selecting suitable problem material and in working out methods of evaluating or scoring the responses. The time would be well spent, however, if it produced a study that would be accepted by most as representative of the effectiveness of this amount and type of training.*

The scenes employed in an evaluational study should be reasonably complex, and should incorporate objects of varying retinal subtense and contrast. They should not include extremely unusual scenes, and each should be presented with a verbal introduction that would serve to establish in the subjects an appropriate set.

It should then be possible to determine whether a man has seen and recognized within the immediate past members of a varied group of objects so presented. Thus, the evaluation problem may be soluble by placing groups of completely untrained observers in the darkroom for 40 minutes, after telling them that they will see a series of scenes projected on the illuminated are before them and instructing them to observe carefully what they see. At the end of this period, they might be asked to report by means of an intensive questionnaire or objective test (e. g., a completion or multiple-choice examination) how many aircraft they saw, how many buildings, or trees, or what kinds of objects appeared on the ground, etc. Questions should, of course, be asked about objects that were not in fact shown. Such a test, used in conjunction with indoctrination periods of varying lengths according to a rigorous control group design, may be expected to yield data enabling us to evaluate the efficiency of the training period in increasing the skill of trainees to see "in the dark."

Objections may be raised to such a procedure for validation. Simple observation of projected material is by no means equivalent to localizing oneself and to performing complex tasks efficiently under low levels of illumination. No movements are required of the subject; no depth is presented. The significance of the results obtained is accordingly not as great as might be desired. But such results would be most valuable in guiding us in planning training programs, their content, and their extent.

Training at the Operational Level

At the present time the Working Group is reluctant to outline any specific program for advanced training in night vision, to indicate how long a period of formal training should be given and how often it should be repeated, or to suggest in any detail its content. We do not know the operational problems (which will dictate both need and content), and there is no information available for determining the point at which diminishing returns appear.

*In setting up any such experiment, note should be made of the factors mentioned in R. L. Solomon's paper, "An extension of control group design," Psychol. Bull., 1949, 46, 137-150.

However, we are confident that the value of night-vision training will be amply demonstrated by the evaluation experiments suggested in the preceding section, and that trainees will be shown to benefit by one and probably more sessions of advanced training. Thus, we are in a position to suggest the broad lines that advanced training might take and to advance the types of development that might be undertaken now so that a concrete program can be set up expeditiously when it is deemed necessary.

Operational training should be given in the last specialized phases of the training of air personnel. It should be given insofar as is possible to groups made up of members of individual air crews or to similar organized groups.

Second, the specific training equipment and methods should require activities as similar as possible to those demanded of the personnel in operations. A variety of procedures will be necessary, then, to meet the special needs of each type of personnel. Since we have little information on the operational situations in which night vision may be needed and on the classes of personnel affected (pilots, gunners, ground crew, etc.), we cannot suggest any specific procedures at the present time -- although it is obvious that each type of personnel will probably specialize in different visual motor tasks, and hence require different training techniques.

Third, no more than a brief review of the subject matter of the indoctrination period should be presented, although the principles will be reiterated frequently in practice on various visual targets appropriate to each trainee's specialty.

Fourth, heavy use of projected motion-picture films (preferably some in color) should be anticipated, and equipment should be developed for their utilization.

Fifth, a wide variety of materials should be employed.

Sixth, hazards to good visual performance (e. g., dirty canopies, faulty illumination, illusory movement, losses of the horizon through faulty adaptation) should be stressed. The use of glasses, to eliminate night myopia, and of paredrine, to produce maximal pupil apertures should be mentioned, if there is a possibility that the men will be provided with such aids.

Seventh, as operational problems change, training procedures should change, with older methods dropped and new ones added. Training equipment must keep abreast of practice.

Eighth, the equipment should be kept as simple, as easily repaired, and as familiar as possible. Where already existing trainers of other sorts can be readily adapted to the purposes of night-vision training, this should be done.

Finally, if training is to be carried on at advanced operational bases, special materials will doubtless be needed.

In these terms, there is a broad field for development. Training cockpits, very low-transmission goggles, night gunnery trainers, all suggest themselves. Considerable ingenuity and operational knowledge will be demanded of those concerned with developing advanced night-vision trainers.

Closing remarks

The Working Group wishes to express its satisfaction with the interest and activity shown by the School of Aviation Medicine with respect to night-vision training. The members of the staff of this organization are showing a considerable grasp of the problems involved

and ingenuity in coping with them. We wish to express our thanks for the cooperation given us by this group, and especially to Colonel Victor A. Byrnes, USAF, and to Brigadier General Otis O. Benson, Jr., USAF, for their helpfulness and kindness in facilitating our work at Randolph Field.

William S. Verplanck, Chairman
E. Parker Johnson
P. Robb MacDonald
Austin H. Riesen

Discussion

Col. Byrnes commented that the Air Force had accepted the report of the working group on night vision training and was actually going ahead with the program recommended by the working group.

Mr. Middleton asked whether the complications introduced by the use of color transparencies were necessary?

Col. Byrnes commented that the use of color transparencies was necessary in order to demonstrate to the trainees that color perception is lost at low brightness levels.

Dr. Verplanck commented that the working group did not intend that all transparencies should be made in color. Dr. Verplanck commented that since brightness shifts as a function of color in the twilight brightness range, color transparencies are essential in order that adequate training at twilight brightnesses can be accomplished.

Dr. Bott asked for clarification of the position of the committee with respect to night vision testing and night vision training. Dr. Bott asked if it was the concensus of opinion in the committee that mass visual training be employed instead of mass testing.

Col. Byrnes replied that as far as the Air Force was concerned, a program of mass night visual training was being substituted for a program of mass night visual testing for flying personnel. The night vision training program is not to be employed with ground crews or with gunnery personnel.

Dr. Gordon asked how one could expect to evaluate a night vision training program if there were no means of testing night vision ability.

Dr. Verplanck agreed that it is of course necessary to develop a test for evaluating night vision training. Dr. Verplanck emphasized, however, that the present tests of night vision ability employ simple visual functions which bear little relation to the kinds of visual jobs which must be performed in the military at night.

Dr. Gordon stated that Dr. Verplanck was apparently not against night vision testing as such but rather against testing simple night vision functions.

Dr. Uhlaner emphasized that AGO does not consider the question settled as to whether night vision testing or training alone will provide the best solution to problems of vision.

Col. Byrnes emphasized that the present report was concerned only with night vision training and was not intended to be concerned with the relative desirability of night vision testing and training.

The report of the working group on night vision training was accepted by the Vision Committee for official transmittal to the liaison representatives of the Committee.

SUMMARY OF

Brig. Gen. Otis B. Schreuder's talk
entitled

"THE VISION PROGRAM OF THE AIR MATERIEL COMMAND"

Gen. Schreuder began by describing briefly the general mission of the Air Materiel Command. The Air Materiel Command's mission is to provide logistic support to the Air Force, that is, the Air Materiel Command is responsible for all procurement for the Air Force. To carry out this mission, the Air Materiel Command has eight materiel centers in the United States.

The medical service of the Air Materiel Command has as its mission to support the general mission of the Air Materiel Command. The medical service has two general programs, one for the military personnel and one for approximately 150,000 civilian employees of the Air Materiel Command. In the case of civilian employees, the medical service is limited to the treatment of on the job illness or any injury incurred in the line of duty. In the case of military personnel, there are hospitals and dispensaries.

During the last year, the vision program of the medical service of the Air Materiel Command has been expanded. Problems encountered by ground personnel rather than flying personnel are to be discussed today. Many problems present themselves in this connection. There are three major phases of the program which might be listed as follows: (a) regulation of protective eye-wear (b) visual selection, and (c) standing structions for traumatic eye injuries.

In connection with protective eye equipment, a variety of problems arise. How should lenses be specified? It is not desired that plastic lenses be excluded by the specifications since it is possible that sufficiently heavy plastic may be developed, to provide adequate eye equipment. There is the further question of frames for eye protection wear. Heavy metallic frames are not popular; plastic frames are much preferred. The difficulty is that lenses may be ejected from plastic frames by accidental impact.

Another problem is the recommendation of filter-type lenses to be used by certain Air Force personnel. Too many people ask for sunglasses. However, in some jobs, there is a real problem of reflected glare and some kind of specification of protective filter-type lenses is needed in these cases. It appears that the intensity of the reflected glare is important rather than the intensity of general illumination.

Visual selection by a machine screening test is being used for the flight examination at the present time. It has been used for the evaluation of civilian employees prior to employment and for placement of employees for specific visual tasks. Surveys indicate that individual visual difficulties exist among the personnel of the Air Materiel Command. A screening program is being adopted for employees who have not been tested for visual difficulties within five years. It is found that this examination definitely improves the ability of the employees to do their job.

In many of the smaller Air Materiel Command posts, only an industrial nurse is on hand and therefore, standing orders must be provided for the treatment of various traumatic eye injuries. Specification of the standing orders to be used in various kinds of traumatic eye injuries are the responsibility of the medical service of the Air Materiel Command. The standing orders are set forth in a manual, copy of which follows.

STANDING ORDERS
FOR TRAUMATIC EYE INJURIES IN
OUT-PATIENT MEDICAL FACILITIES AIR MATERIEL COMMAND

Section I

EYE ACCIDENTS AND INJURIES

First-Aid Treatment at the Scene of the Accident

A. Foreign Bodies Entering the Eye:

1. All cases complaining of foreign objects in the eye should be sent to the dispensary. No attempt should be made to remove a foreign body except at the dispensary. If individual has been exposed to chemicals - liquids or fumes - and there is a marked burning sensation, the eyes should be thoroughly flushed with water at once, using a Benson Eye-Irrigating Unit.

2. An industrial nurse or doctor should anesthetize the eye with 1% pontocaine solution. Using a cotton applicator, an attempt should be made to gently remove any foreign body discovered, from the lids and/or cornea. If successful, a small amount of 10% sodium sulfacetamide ointment is instilled into the conjunctival sac and the eye covered with a patch for 30 minutes. Patient should return the following day for further observation before final release.

3. If the nurse is unsuccessful in removing the foreign body, especially if embedded on cornea, the patient should be transported to an ophthalmologist for further treatment. Cover with patch before letting leave the dispensary, if a local anesthetic has been used. No medication.

4. In presence of excessive irritation in eye where foreign body was removed at dispensary, 30% sodium sulfacetamide solution used TID is often helpful.

B. Traumatic Injuries

1. (Lacerations of eyeball or puncture wounds of eyeball) should not be touched at the site of the accident, but sent directly to the medical dispensary. A piece of clean gauze may be placed over the eye. The patient should be told to lie flat on his back and not help in his removal to a litter or squeeze his eyelids.

C. Flash Burns or Thermic Burns

1. Flash burns or thermic burns of the eye should be sent directly to the medical dispensary without medication. Persons with hot pieces of metal sparks in the eye should be sent directly to the medical dispensary without medication.

D. Chemical Solutions, Chemical Solid Particals or Irritating Chemical Fumes Entering the Eye:

1. It is to be emphasized that irrigation should first be instituted out in the plant where the injured employee is working. Assisted by other workers, the man who has gotten a chemical in his eyes (who is in pain and has a lid spasm) should be led to an irrigating unit. Here, his lids must be carefully forced open, and his eyes copiously irrigated. Washing the man's face with a bubble fountain stream

will not help his injured eye and will only delay things. The lids must be open in order to wash out the chemical. The Benson Eye-Irrigating Unit or a pail of water into which the man ducks his head or an equivalent can be used.

2. From the department where he works, he should be rushed to the plant dispensary, where, after a local anesthetic has been instilled, the injured man's eyes should be again irrigated copiously, for from 10 to 15 minutes, with normal saline solution. Special care should be taken to get the solution up under the lids and in the edamatous folds of conjunctiva where particles might be lodged.

3. Following the above first-aid-measures, the patient should be transported by ambulance to the hospital, and treated by an ophthalmologist, if one is availabe. If no ophthalmologist is available, treatment should be carried out by the industrial physician according to pre-arranged standing orders of the ophthalmologist.

Section II

DIRECTIONS FOR INDUSTRIAL PHYSICIAN

A. Abrasions to the Cornea:

1. Carefully examine the eye for foreign bodies with good illumination and magnification.

2. Stain the eye with sterile fluoroscein solution to bring out the extent of injury. If lesion stains apply 30% sodium sulfacetamide solution every hour during waking hours and 10% sodium sulfacetamide ointment prior to sleep until lesion no longer stains.

   Patient should report back to see if eye:

   (a) Still stains

   (b) There is circumcorneal injection

   (c) If there is, refer to ophthalmolgist

B. Corneal Burns by Hot Particles

1. Examine the eye carefully with good illumination and magnification.

2. If scale is still seen to be attached to the cornea, treat exactly like foreign body case.

3. If scale is not there but staining or abrasion treat like in A.

C. "Flash" Burns (This is a very painful irritation of the eye due to over-exposure of the eyes to ultra-violet radiation as occurs in welding and is akin to a severe sunburn.)

1. Carefully examine the eye for foreign bodies (30% of alleged "flashes" in shipyards during war were actually foreign bodies) or evidence of an abrasion which might be present that takes a stain.

2. If the eye is negative for other factors, apply two or three drops of local anesthetic in each eye.

3. Apply ice cold wet dressings to the eye for 10 minutes. (Never apply ice itself to the eyes.)

4. Insert Holocain Adrenalin ointment.

5. If symptoms persist, refer case to ophthalmologist.

D. Penetrating Foreign Bodies or Puncture Wounds to the Eye.

1. If perforation occurs (often detected by)

    (a) Collapse of the anterior chamber

    (b) Bleeding into anterior chamber

    (c) Extrusion of iris or tissue

apply dry sterile dressing and refer case to an ophthalmologist at once as a stretcher and ambulance case.

2. Never put medication into eye sustaining perforation injury. If the patient is in severe pain, give morphine sulfate (1/4 gr) by hypodermic.

E. Contusions to the Eye (a contusion to an eye can cause serious damage)

1. Ascertain if the patient notices any disturbance of vision in the eye.

2. Test the pupil to see if it reacts actively to light. Compare it with the uninjured eye.

3. If the eye reacts abnormally, refer to ophthalmologist. Otherwise, apply cold packs to the eye.

4. Apply an eye patch if a laceration of the lid or a conjunctival tear occurs and refer to ophthalmologist.

5. Patient should report any subsequent disturbance of vision.

F. Thermal Burns to the Eye

1. Burns to the skin about the eye are best treated by application of sterile vasilene dressing or dry sterile dressing if the former is not available.

2. Burns of cornea - stain the eye with sterile fluorescine for suspected or detected burns to the cornea.

3. Burns of caruncle, even though minor, send to ophthalmologist. DO NOT put ointment in.

4. Every case with severe corneal involvement should be referred to an ophthalmologist.

5. If minor staining at edge of cornea or conjunctival tissue occurs, apply sulfacetamide 30% aqueous solution one drop every hour and cortisone 0.5% aqueous suspension one drop every hour, on alternate half hours while awake. Sulfacetamide 10% ophthalmic ointment will be applied prior to sleep.

G. Chemical Burns

1. Irrigate out at works site (normal saline).

2. Irrigate 15 minutes by nurse in dispensary.

3. Cover with patch and send to ophthalmologist.

4. If minor exposure (see F 5).

H. Special Memos.

1. The use of 2% fluorescein solution in the eye is to ascertain the extent of injury to the cornea. Use on an applicator wound with cotton. Solutions should be cultured every two weeks to rule out contamination. If contaminated, make new solution.

2. When a local anesthetic (1% pontocaine, 2% holocaine or butyn solution) is used in the eye for any reason whatsoever, always patch the eye for at least 30 minutes.

3. ALWAYS TRANSFER ANY EYE SOLUTION FROM STOCK BOTTLE INTO STERILE MEDICINE GLASS BEFORE USING.

4. Use sterile eye dropper for each case.

5. Wash hands after handling every eye case.

6. All ordinary eye preparations should be kept at atmospheric or ordinary room temperatures -- NEVER under refrigeration when stocked. Some antibiotics when diluted for topical use must be kept in refrigerator.

7. Most acid burns produce instantaneous damage and are not, as a rule progressive in effect on tissues. Alkaline burns are nearly always progressive and often dangerous for this reason.

Discussion:

Dr. Sloan asked Gen. Schreuder if the Air Materiel Command was using the standard Bausch & Lomb Ortho-Rater or the Armed Forces Vision Tester for visual testing.

Gen. Schreuder reported that they were using the standard Bausch & Lomb Ortho-Rater. Gen. Schreuder reported that some of the vision testers are becoming available to the Air Materiel Command.

Dr. Sloan cautioned Gen. Schreuder that the early models of the vision tester which she had had occasion to examine were not satisfactory from several mechanical standpoints.

SUMMARY OF
DR. BRIAN O'BRIEN'S PAPER ENTITLED

"A PRELIMINARY REPORT ON THE RESOLVING POWER OF THE RETINA"

Dr. O'Brien reported that he had long been interested in studying the resolution of the retina, unaffected by aberrations of the image forming apparatus of the eye. It is virtually impossible to study the characteristics of the retina alone with the usual type of experiment. Resort has been made to an optical trick. The trick involves utilizing the grating-like image of a line source produced by the interference pattern of two slits of variable separation placed before the pupil of the eye. By varying the separation of the two slits, one can determine the separation at which the retinal pattern can be resolved into a series of parallel lines. Measurements have been carried out in this way with different wave lengths of light and the results are essentially always the same, namely that a row of cones must be inactive in order for resolution to occur.

Discussion:

Dr. Judd reported the following interesting phenomena which may be observed with a point source object and variable slits of the sort described by Dr. O'Brien. If a blue point source is viewed through the slits, one sees a line of points. Each point in the line of points looks blue even though presumably different cones are being stimulated in each case.

Dr. Kenneth Brown asked Dr. O'Brien to comment on the relation between his results and the measurements Riggs has reported of the extent of physiological nystagmus.

Dr. O'Brien reported that he had great faith in Dr. Riggs' measurements of physiological nystagmus. Dr. O'Brien emphasized that the extent of oscillations found by Dr. Riggs is smaller than the separation of cones and that there is no apparent contradiction between the two sets of experimental results.

Dr. Riggs stated his agreement with Dr. O'Brien. He noted that physiological nystagmus is of sufficiently small magnitude so that it does not necessarily blur resolution targets significantly. Dr. Riggs stated that this does not detract from the central interest in physiological nystagmus because of visual tasks like stero acuity and vernier acuity where problems of "local sign" are involved.

Dr. Blackwell expressed interest in Dr. O'Brien's finding that the retinal resolution did not depend on wavelength. Dr. Blackwell noted that various lines of evidence suggest a different population density of receptors responding principally to different wavelengths which would lead one to expect differences in retinal resolution as a function of wavelength.

Dr. O'Brien agreed that this constitutes an interesting problem.

SUMMARY OF
MR. JOHN C. FAYLOR'S TALK ENTITLED

"PROBLEMS ENCOUNTERED IN SEEING IN THE ARCTIC"

Mr. Faylor described in some detail the visual difficulty encountered in the Arctic which was been called "white out". This experience occurs on overcast days in areas which are entirely snow covered and in which there is little or no vegetation projecting above the snow. In the absence of direct sunlight there are no shadows and thus the entire visual field is extremely uniform in brightness. Under these conditions, personnel become unable to judge depth and indeed may become completely disoriented spatially. Some of the men who have experienced "white out" describe their experience as that of "a goldfish swimming in milk".

Mr. Faylor emphasized that the problem is of extreme importance to the Army in its Artic operations and that some means must be found to provide personnel operating under these conditions with reasonable depth perception.

Discussion:

Dr. Miles stated that the problem of "white out" came up during the last war. One technique which has been tried is to shoot a harpoon out ahead with a black line attached to it. The black harpoon line resting on the snow gives a definite cue to distance and the person may walk toward the harpoon with confidence of depth relations. When he gets to the harpoon, he shoots the harpoon forward, thus progresses slowly through the Arctic "white out".

Dr. Miles described another technique which had been used, namely to drop flags from aircraft along the Arctic surface. The flags provide definite cues to distance and one can proceed through an area which has been marked with flags with considerable confidence. The flags which were employed were seven feet long and thirty inches wide.

Mr. Faylor replied that bush pilots in the Arctic had long employed a technique similar to the flag technique to aid them in landing. The pilots carried a supply of evergreens with them. Just prior to landing, they would circle the landing field dropping the evergreens to provide stimuli for depth perception.

Dr. O'Brien stated that he had an idea which might be employed but he rather imagined Dr. Paul of the Engineering Research and Development Laboratory had already thought of it. The essential idea is to project monochromatic light from the vehicle which is moving through the Arctic. This light strikes the surface at near grazing incidence and the monocromatic light reflected to the eyes of the driver of the vehicle will show up contours in the snow surface very nicely by shadowing. The source of monochromatic light could very well be provided by using a high intensity searchlight fitted with an interference-type filter. The pilot could then observe through a similar filter. This filter would reduce the diffuse illumination to nearly zero but would permit the driver of the vehicle to receive nearly all of the monochromatic radiation which returned to his eyes. It would thus be possible for the driver to select out radiation which produced shadows in the day time.

Mr. Faylor thanked Dr. O'Brien for the suggestion and said that the idea seemed to him to warrant definite evaluation.

METHODS OF USING BINOCULARS*

Walter R. Miles, Yale University

Statement of Problem

The use of binoculars as an aid to vision in the prompt and detailed observation of distant objects has long been a standard practice in military and other pursuits. The ordinary observer brings his binoculars to his eyes after having located some object or area which he wishes to examine in more detail. This supplementary use of the glasses permits him to employ his full visual field and natural seeing habits part of the time, and provides a better opportunity for orientation in the general visual environment.

When binoculars are used at the eyes continuously the visual field at any moment is restricted. The observer, unable to make natural use of cues from wider peripheral vision, may have the uneasy feeling of missing items which could be discovered by natural vision. Shifting the glasses from field to field in order to cover a wider area seems to constitute a laborious method of exploration when the naked eye could deal with the total area in terms of a few rapid fixation pauses. Hand-held glasses are almost never free from vibration, especially so if the period of looking is long continued. Under daylight conditions the observer is aware of this vibration, and finds the visual effort to compensate for it and the bimanual effort to hold the glasses steady, a tiring process when long continued. Some

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Assistants to Dr. WRM on Navy Contract N7 onr-288 T.O.V.

- Dr. Lloyd H. Beck, Consultant
- Dr. Catherine C. Miles, Consultant
- Mr. Leonard Taddei, Expediter of Construction and Crew Organization
- Dr. Meyer Samson, Target Specialist
- Graduate Student Assistants:
  - Lawrence Krueger
  - William Cone
  - Charles R. Porter
  - Frank Auld
  - Frank C. Huntington

Medical Student Assistants:
- Ralph Gofstein
- W. Robert Adams
- Dr. Herbert Axilrod
- F. R. Allen

Other Assistants:
- Roger Alling
- Marion U. Huntington, Secretary
- Richard M. Brownwell
- Mary Gaudio, Recorder

Target Station Crewmen:
(Partial list)
- Attilio Gambardella
- Raymond Hartmann Jr.
- Richard L'Ecuyer
- Albert J. Oneto, Jr.
- Alphonse Manna
- William Welch

lookout tasks require only occasional use of the glasses, while others seem to demand continuous use of them. However, assumed requirements constitute no barrier to our examination of the relative merits of these two general methods of using hand-held binoculars.

The discontinuous (N) and the continuous (B) methods of employing binoculars may be studied in reference to their relative efficiency when used in some defined visual task. Let us suppose that the observer is instructed to report the orientation as promptly as he can of visual targets that appear at five field stations which are distributed over an angular distance of 36 degrees. The five stations are easily distinguishable from each other and from the general background which is the skyline of a small city (New Haven). The immediate

Figure 1. Top view. Regular Leica 35 millimeter photo on fairly hazy day showing the portion of the New Haven skyline used for target station locations in experiment on methods of using binoculars. The positions of the five stations numbered from left to right in the figure have been sketched in ink to make them visible in this reproduced photograph. Also the pre-fixation position on the tallest building, Harkness Tower, is indicated by a cross with a dot above it. This view was taken from a point on the roof about ten feet forward and ten feet to the left of the observer's position. Lower section. A telephoto view showing in more detail the position of station 5 on the distant horizon of Indian Head as seen between Bingham Hall and Taft Hotel.

At the expense of the contract a large Elm tree was purchased and removed from a position which obscured station 3. It was not possible to deal similarly with the Taft Hotel which was rather too near station 5 for ideal target experiments.

surrounds of the visual targets are white as seen against the sky, and for the observer, are of equal angular size for all five stations, which vary in radial distance from him. The surrounds, as square white objects, are readily visible to the naked eye, but the visual acuity objects, themselves, two black parallel bars, at the centers of these white fields, cannot be resolved without the aid of the binoculars. Stations 1 and 5 represent, respectively, the extreme left and right of the 36 degree lateral range (See Fig. 1). The top of a tall stone tower near the middle of the range is to serve as the pre-fixation position for each and every test. Station 3, slightly at the right, and lower than the tower, is not in

the field of view when the binoculars are trained on the pre-fixation position[1]. The tests are administered in groups of five, one at each of the stations, viewed in random order, after which the targets are changed according to a scheduled random order at each station. Each subject after preliminary instructions and practice in shifting his gaze from the tower top to the stations as called for by number is to use either the N or B methods, as requested. Before each groups of five tests he is told which method to use according to a random order made out for each subject. In method B the observer holding the binoculars with both hands looks through them at the tower top and after a ready signal hears the number of one of the stations called by the experimenter who at the same time starts a timing mechanism. The observer with the glasses at his eyes turns promptly to the station called, and on fixating the white square says "on", then if he judges the bars to be vertical he responds "up", or if horizontal, "down". After his resolution response he turns back to the tower, looking through the glasses ready for the next test. The experimenter stops one hand of the timer at the response "on", and the other timer hand at the second response, "up" or "down". An assistant records the response direction and the times as read off by E. Then the next test is given. After the fifth test there is a break and 0 takes the glasses from his eyes and rests while the targets are changed. Method N involves visual use of the binoculars only at the target. 0 holds the glasses in a ready position with both hands and looks over them at the tower. Promptly after the station signal he turns eyes, head, and trunk to locate the required station, and then brings the glasses up. Finding the white square he responds with "on", and then gives his judgment of target orientation. The glasses are then lowered, and he returns his natural gaze to the tower to await the next signal. When all five stations have been inspected, there is a break and the glasses are lowered from their usual ready position just below his line of sight.

Analysis of the eye behavior for the two methods shows some differences between N and B which call for scientific appraisal in terms of promptness and correctness of perceptual response. We note that method N provides an unrestricted lateral visual field at the moment of seeking the signalled target station. The naked eye can move quickly and find its new position, but the head and shoulders must also be turned so as to face the target. The binoculars are then raised the one inch or more necessary for vision through them, and at the moment the glasses are brought up vision is interrupted. The eyes must adjust to the new optical media, again find the desired fixation point, and guide it to the central portion of the field of view. These coordinations of eyes, head, trunk, and hands with vision guiding them tend to take place almost synchronously after a little practice. In method B the preliminary fixation field is limited to seven degrees, and no one of the five stations can be seen at the same time, in peripheral vision. The subject must explore for the required station by moving the glasses down and to the right, or down and to the left. The object field moving rapidly as seen through the glasses produces optic nystagmus, i. e., the eyes jerk back and forth in their attempt to maintain fixation, see Figure 2. During the period of nys-

Figure 2. First records of optic nystagmus from turning with glasses at the eyes, taken at Yale University, 1942. Reading from the bottom of the records upward, the subject first turned to the right and then to the left. The two non-nystagmic records at the left of the figure are really one record shown in two parts and represent the eyes first looking straight ahead, then 5, 10, 20, 30 and 40 degrees to the right, followed in the second record by looking back to the 30 degree position, 20, 10, 5 and zero, then continuing 5, 10, 20, 30 and 40 degrees to the left. The two nystagmic records at the extreme right in the figure illustrate optic nystagmic results from turning very quickly first right and then left.

[1]The target - station layout can perhaps be most clearly and readily understood from the section of Yale-New Haven map included in this report.

tagmus vision is blurred, but recovers promptly when the motion of the glasses is stopped. If the motion is stopped before the target comes within the field of view, another shift of the glasses with its accompanying short period of optic nystagmus is necessary. If the first rapid motion of the glasses brings the desired target within the field of view, then a slower motion is ordinarily used to bring the target to the center of the field. The absence of wide peripheral view and the occurrence of optic nystagmus during rapid shifts of the glasses, characterizes method B, while the N method requires delay in bringing the glasses to the eyes and adjustment of vision through them. It was predicted that the B method would be quicker for targets near the pre-fixation point, and probably as long or longer than N for the more extreme targets. These differences, if present, should show up in the on time results more prominently than in the total or resolution times. In reference to accuracy of response judgments it was predicted that N might yield a higher percentage since it requires the subject to make a fresh adjustment to looking through the glasses for each target, while for B there was no such requirement, and in addition the latter method (B) might conceivably suffer handicap from a hold-over effect due to the factor of optic nystagmus.

Experimental Conditions and Materials

The observations here reported were all made during the month of July under what may be described as favorable weather conditions. Local weather bureau forecasts were carefully checked for each succeeding day and usually we were not compelled to cancel our planned testing sessions. However, this precaution of course did not proclude variations in atmospheric haze. As a rule, four subjects served on each experimental day in the afternoon between 12:30 and 4:30 when they were tested one man at a time each for a period of about one hour. The targets were all placed so as to receive direct light from the sun during the entire afternoon session. Direct sunlight did not fall on the observers who were protected on either side by low walls and by canvas overhead. All of the targets with their immediate white surrounds were viewed against the sky except those presented at Station 3 which is described later. Out of door temperatures were comfortable, requiring neither hats nor jackets, and the same arrangements that shielded the subject from the direct sun also gave some protection from wind. In general, these outside arrangements seemed optimal for our purposes.

Target Station Locations

In choosing locations for target stations on the skyline of the central part of New Haven the following factors had to be considered: angular separation of stations, prominence or distinctive character, distance from the observer, freedom from interfering aerial wires, freedom from smoke, accessibility and safety for target crew, and freedom from the annoyance of visitors who either at experimental intervals or between times might be a nuisance. Finally, the tops of four Yale buildings were selected as meeting our requirements, and permission was granted for their use. For the fifth and most distant station which was at the extreme right of the range the Park Commissioner of New Haven granted us the use of a hilltop, Indian Head, lying just to the right of the geological eminence known as East Rock. The locations of these five areas and of the pre-fixation tower in relation to the skyline and city ground plan are indicated in the photograph, Figure 1, taken from the point of view of the observer and on the map. Stations 1 and 5, respectively, represented the extreme left and right of the 36 degree angular range to be covered by the observer. Wooden frameworks were erected on the tops of the four buildings and on the rock for the purpose of holding the targets securely when they were presented (see Fig. 3). These structures designed to be relatively free from vibration varied somewhat in size according to the distance from the observer and in relation to the heights of the parapets of the buildings. For the nearer stations 1, 2, and 4, the frameworks were relatively small, since the target squares to be held by them

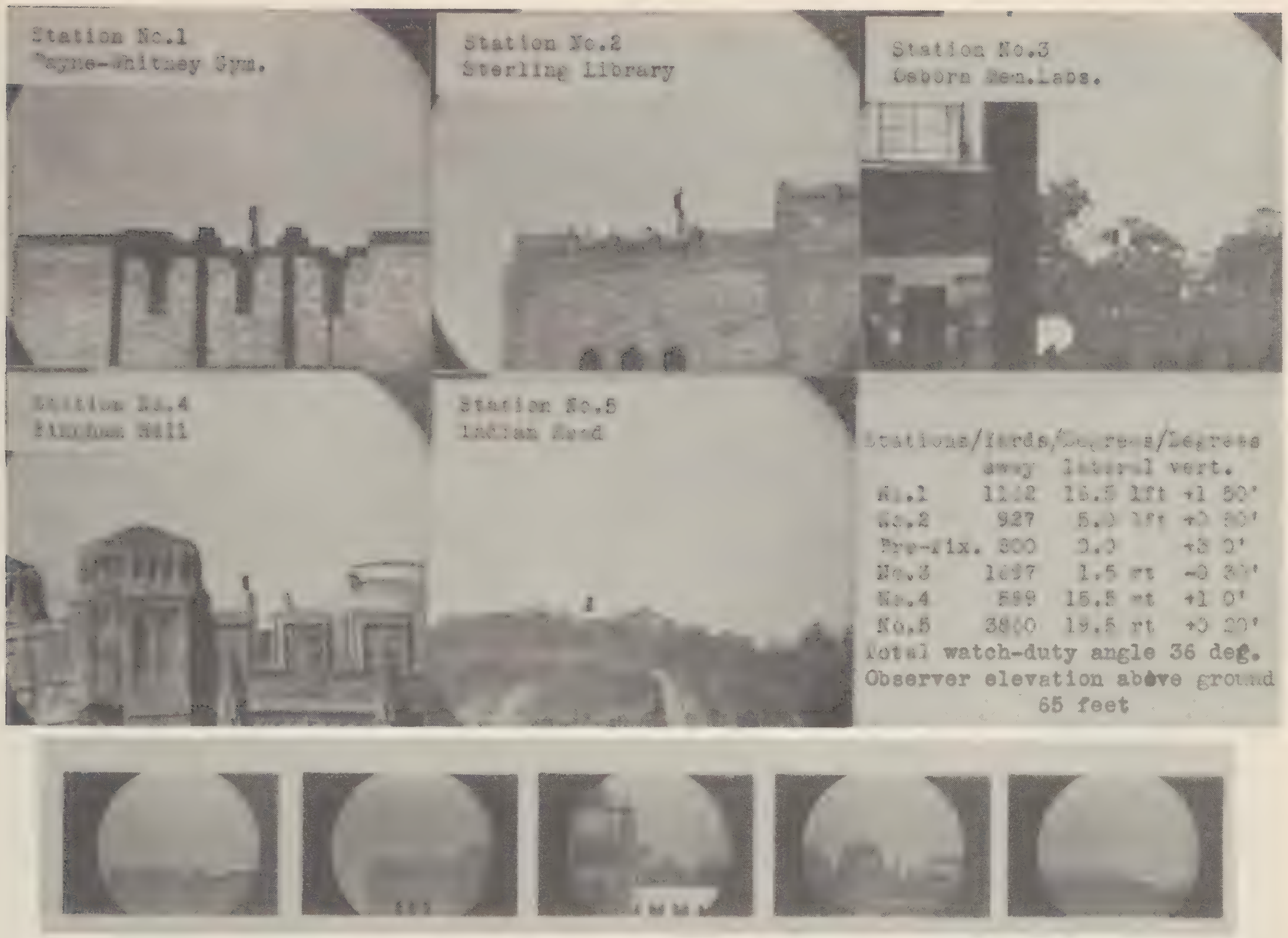


Figure 3. This composite figure shows enlarged telephoto views of the five target stations designating the building or location of each. The actual telephoto views were taken by using the regular Leica camera with lens set at infinity and an opening of 3.5 attached before the ocular of a 30 x shipmaster's telescope. The series of pictures illustrated at the bottom of the figure is representative of what were taken following the observations of each subject when half of the target square was covered with black velvet for estimating the influence of haze in reducing contrast. The small data table incorporated in this illustration shows the distance from the observer of each target position given in yards, the no. of degrees lateral each target position was from the pre-fixation position and the relative elevations of the target positions from the position of the observer who occupied a station 65 feet above ground level.

were small enough to be easily manageable by the attendants. For Station 3, at the top of a rather narrow stone tower (Osborn Laboratories), the structure had to be larger, as it constantly carried the white panel against which the targets were placed. The targets themselves for this station were mounted on thin metal panels and when placed in the center of the permanent square were held in position by magnets. Station 5, the most distant one (about 2 miles), demanded a heavily built structure (see Fig. 4) braced with cables from the four corners of its platform and having a total height to the top of the target panel, of about thirty feet above the ground. Here again, as for station 3, the target squares were of thin metal, and were held in place at the center of the surrounds by permanent magnets mounted on the back of the large masonite panel (Fig. 5). The lateral angular distances from the pre-fixation position for the five targets and their relative radial distances from the observer ($\pm$ 5 yards) and their elevations relative to the observer are given in Figure 3, together with telephotos of the five target positions. Number four was the nearest station and number 5 was the farthest away.

Station 3, at 1697 yards distance was only 1.5° to the right of the tower. This station, while being the nearest to the pre-fixation point, was the most difficult of the five to distinguish in relation to its general background, which consisted of tree branches, and closely adjoining structures, so that the target square was not seen against the sky (see Fig. 3) as

Figure 4. Station 5 erected on Indian Head was sufficiently high so that the target square was seen by the observer against sky area. This figure illustrates target A in position so as to be responded to correctly by the subject's saying "down". The insert also a photograph of station 5 shows target F in position for correct resolution response "up". In actual presentation of targets the 3-member crew would be out of sight of the observer, that is, behind the screen. The arrangements for placing the black velvet sheet over half of the target square will be noted in the figure by the lines associated with small pulleys, and the light measuring box is seen at the right in each figure attached to the railing with front white square parallel with the target square.

at the four other stations. At each station the requisite equipment consisted of (1) a set of twelve visual targets enclosed in protective carrying cases, (2) a schedule sheet made out for each subject showing the random order in which the targets were to be presented and the positions (bars vertical or horizontal), (3) a specially constructed lightmeter to measure the over-all sky brightness and also the brightness of the light on the target panel, and (4) heavy black velvet to cover half the panel when telephotographs were made from the observation roof to record the contrast reduced due to haze following each observer's session. Two assistants were required at each station to take care of the routine of responding to signals, placing and checking the identity and orientation of the targets put up, and making the entries of time of presentation and associated readings of the light values. For station 5 three assistants were required, as the signals to this station were by means of Navy blinker light and not by telephone as used for the other four stations.

Observation Station

The observation station was 65 feet above the ground level near the north end of a five story brick building, Institute of Human Relations, and provided an open horizon (city skyline) view of nearly 180° (see Fig. 6). Immediately in front of the subject was a thin concrete wall of waist height extending from a structure at the left to one at the right. Above an open framework of pergola type covered this space which was about eight feet wide. This upper framework was covered with canvas when required to shield the subject from the direct sun. When observing, Figure 7, the subject stood near the open end of this semi-sheltered compartment leaning gently against the wall in front of him, but with no support for arms or trunk from either of the side walls. Immediately behind him was a high stool in which he could rest between sets of five trials. Behind the subject and about five feet away, the recording assistant sat, with the experimenter seated just at her left. A second assistant was present to monitor the blinker light and with his pair of binoculars

Figure 5. The permanent magnets mounted at the center and back of the target square of station 5. The human hand grasping a portion of the left hand magnet will serve as a scale for size.

Figure 6. This illustration represents an early stage in the development of our methods of research for this ONR contract. At this stage the attempt was made to produce objective records of both eye movements and head movements in changing from the pre-fixation position to an announced target position. The method involved the use of a vacuum tube microvoltmeter coupled with an Einthoben string galvonometer which Dr. Meyer Samson is shown operating while a subject is engaged in viewing targets by the B method. The two records at the left in the illustration represent typical records taken with this apparatus. The intervals represented by the horizontal bands across the record are one-fifth second. The record at the extreme right is for a subject showing larger than average nystagmic movements associated with turning with the glass from one station to another. The second record from the left shows nystagmic movements rather smaller than the average associated with these shifts in position of the binoculars. While our assistants in this research found it possible to cooperate adequately for the taking of these records it became obvious that the method was too demanding on the subject to make it practical for application in the main research. Consequently the results presented in this paper are not based on records taken photographically as illustrated in this figure.

checked on the change of targets at all five stations before giving a go ahead signal for the next set of five tests. A third assistant, outside the area occupied by the subject and crew just mentioned, took light readings during the interval when the subjects were observing. The subject was not cumbered by any other apparatus than the binoculars, (see Fig. 7, upper right-hand view) and efforts were devoted to making the subject's test experience a pleasant one.

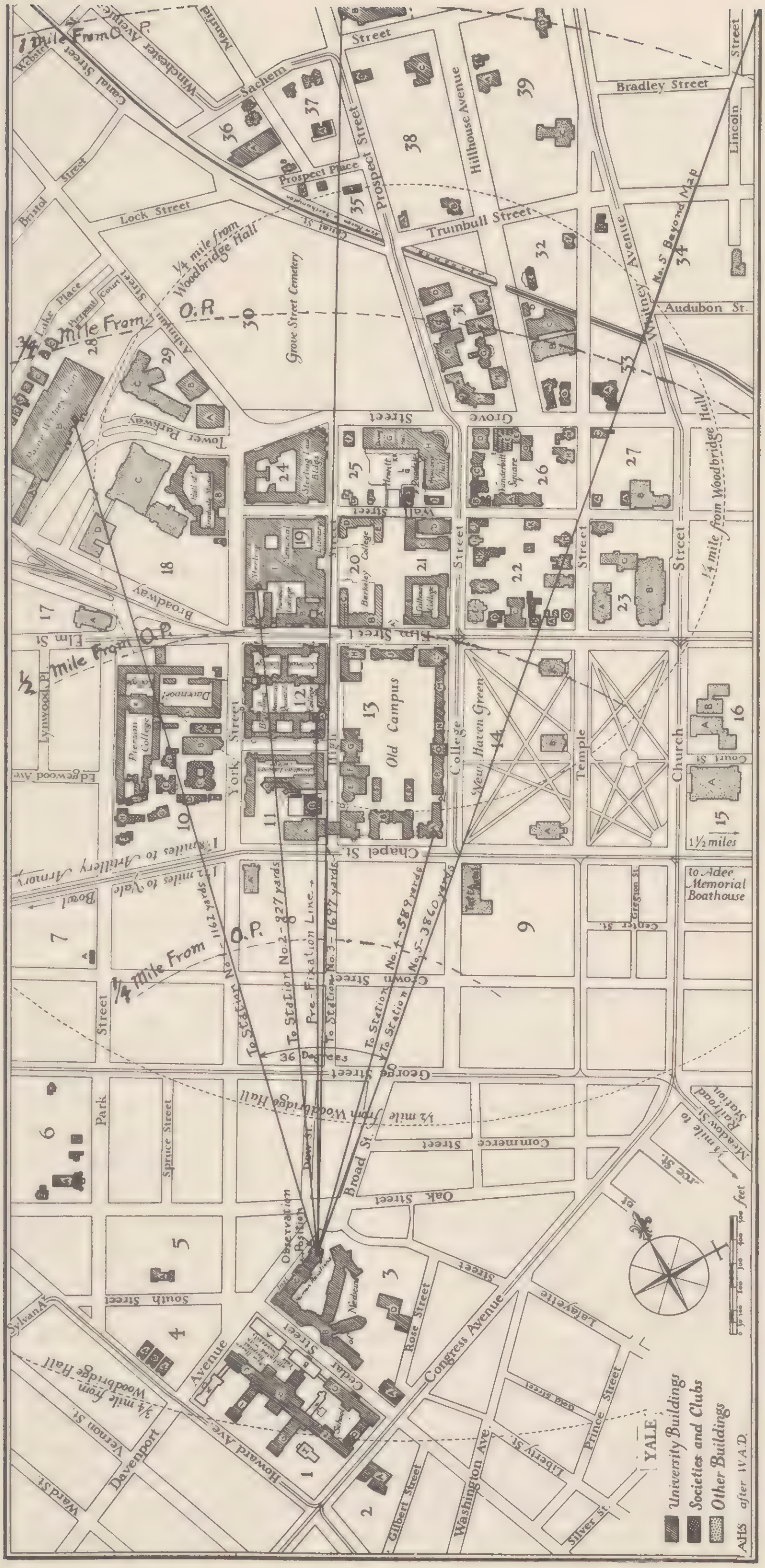
Visual Targets

The targets employed were all of the generally familiar two-parallel-bar type. The length of each black bar was 3 times its width, and the white space separating the two bars

Figure 7. In the upper left-hand picture in this figure a subject is being instructed in reference to the five target areas and the manner in which he is to use the binoculars for methods N and B. In the upper right-hand photograph a regular test is in progress. The assistant at the upper left and near the Navy blinker light has announced that all targets are in position. The experimenter in the lower left has called the signal telling the subject which station to look at. The subject in the upper right is looking at that station and the recorder in the lower left is ready to enter his response after which the experimenter will read off the time values for ''on'' and for resolution response. In the photo at the lower left an assistant is reading the light values for over-all sky brightness and for brightness incident on the target screen by means of the special light-meter devised for these experiments. In the lower right-hand photograph Dr. Beck at the right and his assistant are seen engaged in making measurements of haze density as judged by the registered sky brightness and brightness of the faces of West Rock and East Rock.

was of the same width as that of the individual bars. The two bars with the intervening white space therefore formed a square target object. The critical feature for visual discrimination was the width of the white space between the bars which, at the eye of the observer, subtended an angle one-third that of the total dark squares. The targets were presented an equal number of times with the white space vertical and with it horizontal, and the subject was asked to respond in terms of these two orientation positions "up" or "down". The parallel-bar test object possessed, for this experiment, practical advantages over such objects as the Landholdt Ring or the letter "E", which in dimensional height and width are usually made five times that of the critical subtence angle. The bar targets were both more simple to construct and more convenient in size for transportation and handling at the stations.

Twelve targets were prepared for each station, the required dimensions having been worked out in terms of the distance that each set was to be used from the observation point The objective was to provide five parallel series of targets that at the five stations would subtend equal visual angles at the observer's eye. The twelve targets for each station constituted two series: 6 with near maximal contrast (black bars on white field) but varying in size (width of white interspace) and 6 of constant size but varying in degree of contrast. In the size series target A was the largest and target F the smallest while all six were of equally high contrast. In the contrast series all were of size B, number 6 represented



Section of Yale-New Haven Map showing Target-Station Layout

the greatest contrast used and number 1 the least, but number 6 was of lower contrast than used in the size series, Table 1.

TABLE 1

Test Targets: I Bar width (inches, logs, seconds of arc);
II Visual acuity reciprocal; III Per cent luminous reflectance of bars.

	Size Series						Contrast Series					
Targets	A	B	C	D	E	F	6	5	4	3	2	1
I Bar width:												
Inches*	3.93	3.28	2.78	2.34	1.96	1.65	3.28	3.28	3.28	3.28	3.28	3.28
Logs	.595	.516	.444	.369	.293	.217	.516	.516	.516	.516	.516	.516
Seconds of arc**	60.0	50.1	42.4	35.7	30.0	25.2	50.1	50.1	50.1	50.1	50.1	50.1
II Visual acuity reciprocal:	1.00	1.20	1.42	1.68	2.00	2.38	1.20	1.20	1.20	1.20	1.20	1.20
III Per cent luminous reflectance of bars***:	4.6	4.6	4.6	4.6	4.6	4.6	12.0	19.8	24.6	36.2	59.1	78.7

*Station No. 3 used as example. For the other four stations the bar widths were proportional according to the distances from the observer.

**Calculated on the assumption that the 7 x 50 x 7° binoculars would yield an efficiency of 64 per cent, or a magnification factor of 4.48, in place of 7 times that of the naked eye. The binoculars employed were made in occupied Japan, they bore the Zeiss trade name, "Novar", and had coated lenses.

***The per cent luminous reflectance of the white surrounds may be taken as 88.

Binoculars used in resolution tests under daylight conditions do not provide an increase of efficiency over naked eye equal to the rated magnification of the instrument. Some reported tests with standard 7 x 50 x 7° binoculars have shown a binocular advantage over the naked eye of 2.5. Under laboratory conditions for night seeing the advantage factor of this instrument has been set as high as 6.0. More fragmentary data taken under daylight conditions have placed the factor as low as 1.2, for hand-held instruments. Standard 7 x 50 x 7° binoculars with coated lenses were to be used in our present research and in order to plan the actual target dimensions it was necessary to assume some binocular factor of advantage to be applied to the five size series of targets. We assumed that these binoculars would yield an efficiency of 64% of their 7 x magnification or a factor of 4.48. On this basis trial targets were constructed and tried out at Station 4 in preliminary tests. The results proved satisfactory, and the binocular factor of 4.48 was used in computing the measurements for the size targets at all stations. Bearing in mind the assumed effective magnification factor of 4.48 for 7 x 50 x 7° binoculars, target A at each station was designed to present a critical angle of 60.0 seconds, target B 50.1 seconds, target C 42.4 seconds, target D 35.7 seconds, target E 30.0 seconds, and target F 25.2 seconds. These values, (see Table 1) starting with A at 60 seconds, represent equal logarithmic steps. If target A, viewed through the binoculars, is just resolvable, then the reciprocal of the other targets as just resolvable visual angles measured in seconds of arc from B to F inclusive are 1.2, 1.4, 1.68, 2.0, and for F 2.38. As a concrete example of the actual dimensions, (width

of white space between the black bars), for Station 3, to be seen at 1700 yards, the widths in inches and decimals are: A - 3.93, B - 3.28, C - 2.78, D - 2.34, E - 1.96, and F - 1.65.

The square panels on which the targets were mounted were arbitrarily made about three times the linear dimension of the length of the black bars in target A. Thus, if the black bars in A may be assumed to subtend an angle of 3 minutes, as viewed through the binoculars, then the total panel represented 9 square minutes. And for naked eye vision it appeared as 2 minutes on a side of 4 square minutes of arc. All of the target panels were of this size so that the smaller targets in the size series had relatively larger white space surrounds.

For Station 1, 2, and 4 the targets of the size series were painted on masonite squares. The smooth face was painted with two coats of the best grade of flat white and later black bars were very carefully painted with two coats of the best flat black. For stations 3 and 5 squares of thin galvonized metal were used; they were covered with white cardboard which closely matched the white paint used on the other squares, and the black bars were made by attaching black strips of paper (Color-aid Gray No. 8) which approximately matched the flat black paint. These metal squares for Stations 3 and 5 were relatively smaller than those used at the other stations, since they were to be held by magnets at the centers of the white squares that were part of the structures at these stations. The differences between the white of the cardboard and the white of the paint when the targets were mounted was not detectible at the observation distance.

The contrast series of targets for each station were all constructed on the dimensions of target B of the size series for that station. That is, they were all 1.2 visual acuity targets in terms of size. They were all made from the best quality of white cardboard used as background on the panels. The bars were made by inconspicuously attached contrast papers from a standard series of high quality materials.[2] Originally, eight targets were made for the contrast series. Number 8 was of the same contrast as used in the size series, and in about equal logarithmic steps the contrast series proceeded to number 1, the least contrast that was deemed distinguishable. In some preliminary experiments it was found that using contrast targets 8 to 3 inclusive provided fewer than the desirable number of errors. Therefore, in the regular test series here reported targets 6 to 1 inclusive were used except in the case of two subjects in the control group who were accidentally tested with Nos. 8 to 3,

The percentage luminous reflectance of the Color-aid grays used in making the size targets for stations 3 and 5 and for all the contrast targets for all the five stations were found to match rather closely certain Munsell grays as follows:

Color-aid No.	Munsell Value	Per cent Luminous Reflectance
8	2.5	4.6
7	3.5	9.0
6	4	12.0
5	5	19.8
4	5.5	24.6
3	6.5	36.2
2	8	59.1
1	9	78.1

The chronometer used in timing the subjects was calibrated in tenths seconds, 0.1

[2]Color-aid Co., 329 East 29th St., New York 16, N. Y. Color-aid Grays Nos. 1-8.

seconds. It was an accurate high grade instrument carefully calibrated and in good working order. The subject's "on" response was the signal for stopping the first sweep hand and his resolution response of "up" or "down" the signal for stopping the second hand. The movement of the timer ran continuously. When the time values were read off to the recorder the subject could, if he wished, overhear them. All of the times were recorded by the same experimenter, who was well trained in such matters. The time values presented as results include the experimenter's simple reaction time.

Subjects

Young men of High School education in good physical health between the ages of 18 and 26 and testing 20/20 vision, served as subjects in these experiments. Two groups were employed. One group of 23 from the U. S. Submarine Base at New London were kindly supplied through the cooperation of Captain T. L. Willmon, MC, USN, 0 in C, Medical Research Laboratory. They were selected from submarine crews and all had had some lookout experience in routine service but not under combat conditions, and were quite familiar with using binoculars. They came four at a time in a car with a driver, and after having lunch in New Haven were ready for their afternoon session. They did not receive extra pay for this service. Visual tests with the orthorater were made here in the laboratory after the men arrived, and other tests having to do with personality and interests were given the men by Dr. Catharine Cox Miles during the afternoon while different ones were not serving as observers on the roof in the binocular experiments. These subjects cooperated willingly in the experiments although some expressed the view that the tests were quite unrealistic. Another group of men designated as "Control" or "Untrained" group was secured in New Haven through cooperation with educational institutions and various individuals. These men were selected so as to represent the same age range and as far as possible of about equal educational experience as the men from the naval group, but their experience in the use of binoculars was in most cases minimal. In recruiting the control group it was necessary to specify that the men should have good vision, should not have to wear spectacles, and that they should be in good physical condition with no physical handicaps that would constitute a limitation for their service in the experiments. It was necessary to give visual tests with the orthorater to these men before they came for their experimental test period and if the men qualified make future appointments. These men cooperated willingly; they were paid by the hour for their services.

Procedure and Instructions to Subjects

The subjects were brought to the observation post on the roof individually. The nature of the task was explained to them and they were shown the type of target that was to be used at all the stations, and how the targets would be presented, sometimes with the bars vertical and sometimes with them horizontal. The five target stations were pointed out and the position for the pre-fixation location shown. It was explained that the five stations were designated by number from left to right, one to five. The binoculars were adjusted to the interpupillary distance of each subject and each eye piece was adjusted to the zero position, unless the subject regularly employed a different adjustment than the zero position when using his binoculars for daytime seeing. There were a few subjects among the Navy group who preferred such adjustments and claimed that they regularly used them. The subjects tested the precision of the focus on a number of distant objects including the target squares on Station 3 and 5. The two methods, N and B, for using the glasses were explained and the subject was instructed in the proper manner of holding the glasses with both hands for each method. All of the instructions were given verbally and subjects were encouraged to ask questions in reference to the routine which they were to follow. In this preliminary period they were told to point out the different stations and continued doing this until it was evident that they understood the layout. Then they were given practice for several minutes in the two methods

of fixating the top of the tower as the preliminary position and shifting to the various stations as called for by the experimenter. When it became clear from their practice demonstration that they could, when signalled, move from the pre-fixation position to any one of the stations without mistakes, they were again shown the type of target that they were to look for and were given a short rest. During this interval the recorder assistant using the master telephone on her desk by ringing one number called all four stations, 1, 2, 3, and 4, and asked that target 1 for the subject be exhibited. Also in this interval the second assistant at the blinker light signalled Station 5 for target 1 to be put in place. The subject by naked eye could see the white target squares at all five stations, but could not resolve the bar targets without the use of the binoculars. The subject was told which method to use, B or N, according to the schedule that had been worked out for him. He fixated the top of the tower, was given a "ready" signal, then one of the station numbers was called by the experimenter as he started the timer, the subject moved to the station called, when he saw the white squares through the glasses he said "on", (the first timer hand was stopped) and as soon as he could resolve the target at the center of the square he said "up" or "down" (the second timer hand was stopped).[3] The subject moved his gaze back to the fixation position, the experimenter read off the two time values to the recorder who had already made record of the direction of the response, "up" or "down" as given by the subject. The experimenter again said "ready" and noting the next station to be called on the schedule, called that number to the subject, and so the second test and others following it were made until the completion of the five tests was carried through. The subject then had a short period of rest while the recorder and the assistant in charge of the blinker notified the personnel at the five stations that we were ready for the second target on their several schedules. The subjects were encouraged to be accurate in their responses rather than to be satisfied with a guess. They knew that the targets would occur in irregular order rather than increasing in difficulty. They were not complimented on making short response times, but were encouraged to be as accurate as possible, and to guess only after repeated attempts at resolution. The experimenter did not know the accuracy of any subject during the testing period; this had to be determined later by comparison of the recorded results in comparison with the schedules carried through at the five target stations. The experimenter endeavored to reassure each subject at intervals throughout his test session and could judge the resolution results only in terms of the confidence expressed by the subject in reference to his performance. In most instances it seemed likely that the subject was doing quite well; in a few it seemed probable that he was doing rather poorly.

General Results of Binocular Tests

Twelve targets, six in the size series and six in the contrast series, were used at each station. Target A was used only once at each station with each subject, that is, five times counting all stations. All the other 11 targets were used twice at each station, once presented vertically and once horizontally. Therefore the subject had a total of 10 trials with each of these 11 targets. According to this plan, the total number of trials given each subject was 115, distributed in 23 sets of 5 trials each. The 23 subjects used in each group according to the plan should provide for a total of 2645 test trials. Actually the Navy group made 2641 trials, 4 being defective because of mishaps at stations. The control group made a total of 2644; however, there were 40 of these trials in which targets 7 and 8 were used in place of targets 1 and 2. Therefore in group comparisons the body of data for the "untrained" consists of 2604 tests. The Navy group provides data for 1319 tests made by the B method and 1322 made by the N method. The untrained group provides us 1299 individual tests by the B method and 1305 by the N method. In 19 instances for the trained group and 12 for the untrained individual responses were indeterminate, i. e., the subject could not or

[3] The subjects were all asked to express a judgment "up" or "down" but occasionally the response was "don't know" and some subjects refused to guess.

would not give a response of "up" or "down" for the target. These instances were entered as question marks. In the immediately following comparison question marks were counted as trials and each given a value as one-half an error.

As a first comparison of the relative effectiveness of the B and N methods used as observation techniques with binoculars, we may take the over-all performance of each subject group on the two parts of the test. The Navy group, in a total of 1319 tests by the B method gave 867.5 correct responses or 65.7% right. For the N method in 1322 tests 885 were correct yielding 67.0% right. The difference, 1.3%, in favor of the N method is not large enough to be significant. The untrained subjects by the B method had 1299 tests of which 797 responses were correct, yielding 61.4% right. This group had 1305 tests by the N method with 806 right, which yields 61.7% correct responses. While the difference, 0.3%, is again in favor of N, it is quite too small to be significant. The over-all results are not changed significantly if we discard the indeterminant responses and also responses whether correct or in error that require 20 seconds or more for the subject to respond. In calculating in this manner the Navy group for B gave 65.8% right, and for N, 67.2%. The untrained group show 62.2% for B and 62.4% for N. In this rough general score of correct responses a significant difference in favor of the trained (Navy) subjects appears, although both groups may be said to do almost equally well with the B and N methods.

In reference to the two groups of targets, the size series and the contrast series, the B and N methods also appear to give quite closely parallel results. The trained group got 59% right for the size series with method B and 63.5% right with method N. For the contrast targets the trained group got 72.2% right with B and 70.0% with N. On the size targets the untrained group had 57.8% right by method B and 57.0% right for N. On the contrast targets the untrained group had 64.6% right for method B and 66.2% correct for N. For both groups of subjects the series of contrast targets proved to be easier than the size series, and although the trained subjects did somewhat better than the untrained group, neither group gave definitely better results with method N than with method B.

Results for Promptness of Responses

Let us turn now to a general comparison of the B and N methods in terms of the response times for total, correct and error trials for the entire series of targets, as recorded for the two groups of subjects in Table 2. The values given are in seconds and decimals of seconds, and are group averages computed from the averages for individual subjects. These calculations do not include unresolved, i.e., question-mark responses, nor responses requiring 20 seconds or more for resolution. The application of these criteria eliminated about 1% of the data for each subject group. The reader will note that for the N method the trained group had a total of 1308 responses. The average "on" time response here was 2.50 seconds, the resolution response 5.14 seconds, and the difference between "on" time and resolution time was 2.64 seconds. There is no further need to rehearse in the text the values given in Table 2. It will be seen that the "on" time for trials that resulted in errors and trials that resulted in right responses for each group of subjects and for each method of using the binoculars tended to be a little longer for the errors but not varying more than .06 seconds. However, a difference between the two methods, N and B, stands out clearly. The "on" time when using method N is longer by about 0.16 seconds for both error trials and right trials of the trained subjects. For the untrained group method N is longer than B by 0.30 seconds. These differences in favor of B as the more prompt method reach the criterion of the 1 per cent level of confidence.

Method N when used under optimal conditions, i.e., with the glasses as readily available as possible to the eyes, proves to be slightly but dependably slower (0.16 to 0.31 seconds) than method B in training the binoculars to the immediate targets areas so that the subjects could announce the response "on". But this is not the only consistent difference in

TABLE 2

Average Time (On, Total, Difference) Required by Trained and Untrained Subjects for Recognition of Targets* at each of the Five Stations.

	On Time			Total Time			Diff. Time			Ratio On/T.T On/T.T		
Stations	Method N	B	N-B	Method N	B	N -B	Method N	B	N-B	Method N	B	N-B
Trained Subjects (23) 1	2.44	2.41	.03	4.97	4.90	.06	2.53	2.49	.04	49.1	49.1	0
2	2.50	2.23	.27	5.33	4.51	.82	2.83	2.28	.55	46.8	43.7	3.1
3	2.46	2.00	.46	5.39	4.71	.68	2.93	2.70	.23	45.6	42.5	3.1
4	2.60	2.53	.07	4.93	4.80	.13	2.33	2.26	.07	52.7	52.6	.1
5	2.52	2.50	.02	5.09	5.31	-.22	2.56	2.80	-.24	49.6	47.0	2.6
Averages: Total[1]	2.50	2.33	.17	5.14	4.85	.29	2.64	2.51	.13			
Average[2] time for	2.48	2.32	.16	4.96	4.71	.25	2.48	2.39	.09			
Errors[3]	2.54	2.38	.16	5.69	5.30	.39	3.16	2.90	.26			
Untrained Subjects (23) 1	2.68	2.60	.08	5.62	5.53	.09	2.94	2.92	.02	47.7	47.0	.7
2	2.68	2.20	.48	5.84	4.99	.85	3.16	2.79	.37	45.8	44.2	1.6
3	2.78	2.09	.69	6.19	5.31	.88	3.41	3.22	.19	45.0	39.4	5.6
4	2.80	2.77	.03	5.77	5.78	-.01	2.97	3.01	-.04	48.5	48.0	.5
5	2.79	2.59	.20	6.07	5.83	.24	3.28	3.23	.05	46.0	44.4	1.6
Averages: Total[4]	2.75	2.45	.30	5.90	5.49	.41	3.15	3.04	.12			
Rights[5]	2.75	2.47	.28	5.65	5.28	.37	2.90	2,81	.09			
Errors[6]	2.78	2.47	.31	6.48	6.04	.44	3.70	3.59	.11			
Average Time T-U	-.25	-.12	-.13	-.76	-.64	-.12	-.51	-.53	.01			

*For the group of 23 subjects (trained or untrained) there were 521 to 529 targets presented at each station. N targets were approximately half of this number. B targets approximately half.

1. N for the N-Method cases equals 1308; and for B-Method cases equals 1304.
2. N for N-Method right cases equals 879; and for B-Method right cases equals 858.
3. N for N-Method error cases equals 429; and for B-Method error cases equals 446.
4. N for N-Method cases equals 1310; and for B-Method cases equals 1311.
5. N for N-Method right cases equals 818; and for B-Method right cases 816.
6. N for N-Method error cases equals 492; and for B-Method error cases 495.

response time that appears in Table 2 for our results with both groups of subjects. The resolution response times are also longer with the N method, (see Total Time and Difference Times, columns, N-B). The averages for the resolution times for both errors and rights (also for totals) for both groups of subjects are always longer for the N than they are for the B responses and they exceed the 1 per cent level of confidence. These resolution times of course include the "on" time for each average. The difference times, which are derived values, provide a picture supposedly free from variations in the "on" time averages. For the trained subjects the total difference time, 2.64 seconds for the N, responses, exceeds the difference time for B, 2.51 seconds, by 0.13 seconds; for the error responses of this subject group the difference time for the N method exceeds that for the B method by 0.26 seconds. Similar results were found with the control or untrained group. But N-B for Difference Time in general does not quite reach the 5 per cent confidence level. However, it seems fair to conclude that in addition to the subjects requiring a little more time with N as compared with B to get his glasses and his eyes on the object area he also required with N from 0.1 to 0.2 seconds more to reach the point when he was willing to announce a resolution response. These time differences all appear in the same direction, and therefore seem the more dependable.

We must now analyze the over-all results for promptness of response by the two methods in terms of the individual stations, which as will be recalled required varying amounts of lateral displacement of view from the fixation position: -- Station 1 was 16.5 degrees to the left; Station 2 was 5.0 degrees to the left; Station 3 was 1.5 degrees to the right; Station 4 was 15.5 degrees to the right, and Station 5 was 19.5 degrees to the right. In Table 2 (Total averages) we may turn first to consideration of the "on" time results at the five stations. These averages are for errors and right responses combined. We note that at all five stations both subject groups show "on" response times for N which are longer than those for B. The difference between B and N is most marked in both groups for Stations 3 and 2 which were both nearer the pre-fixation position than were 1, 4 or 5. The five Navy "on" averages for N are closely grouped around their general average of 2.50 seconds, and also for the untrained are closely grouped around their average of 2.75 seconds. The B averages are more widely scattered and indicate that Station 4 was the hardest to reach with certainty. Both groups of subjects show a tendency with N to be a little quicker for the targets to the left of Station 3 than for those to the right of it. In the B "on" responses both groups vary more widely from their respective means for the five stations and the values for the five stations exhibit a pattern which both groups of subjects tend to follow. The shortest B "on" response for both groups is for Station 3 which required the least displacement from the pre-fixation point. Next comes Station 2. Then for the Navy group station 1, 5 and 4, appear in order of increasing time magnitudes. While for the control subjects stations 1 and 5 are practically the same and both definitely slower than number 2 and Station 4 is the slowest of all. Stations 3, 2, 1, and 5 show time values for the Navy group which are roughly proportional to the increase in lateral distance that had to be covered. The untrained subjects tend also to this pattern. Station 4 falls out of line perhaps because it was only four degrees away from Station 5 and subjects had to be on their guard to avoid confusion.

In each group conspicuous lengthening for N over B (or shortening of B in comparison with N) appears for stations 3 and 2. The extreme right-hand column of the Table 2 shows the contrast between N and B here. The major reason for these results appears to arise from the facility of method B for shifting the line of sight across short lateral distances, with one target to the right and the other to the left of the pre-fixation position. Stations 1 and 4 on the other hand, demanding shifts of 15 or more degrees seem to represent in terms of these data about the limit at which the B method can succeed in being just slightly more prompt than N. It seems difficult to understand why Station 5 should have produced such a long resolution response with the trained subjects by the B method, 5.31 seconds, whereas their longest average for any other station was 4.90 seconds. And furthermore, Station 5 for this group, 5.09 seconds, while not the shortest time for the 5 stations, is

distinctly shorter than for Nos. 3 and 2 in the N column. There were 13 of the 23 trained subjects who on Station 5 showed a longer resolution time for B than for N by from 0.1 to 1.1 seconds. There were 16 of this group of 23 trained subjects whose difference time for B was larger than for N. Therefore the average results seem a dependable trend for the group but are not explicable in terms of data at hand.

Performance Variations Among Subjects

As stated earlier each subject made 115 trials. The 23 trained subjects secured through the cooperation of the Submarine Base showed individual error scores that ranged from 19 1/2 (this is counting the question marks as one-half errors) to total of 57 errors, which equals 50% of the trials. There were 5 of these subjects who had less than 30 errors, and 5 who had more than 50. The untrained group of 23 men showed a range of errors from 19.5 to 68.5. Only 3 of these subjects made less than 30 errors and 7 made 50 or above. On target A there were 15 of the trained subjects who made not a single error in the five trials that each had on this target. Seven made one error. Of the untrained 13 made no errors on A; 5 made one error. As was to be expected no other target rated as high a percentage of resolution. Individual subjects showed high degrees of accuracy and consistency. For example, subject T16 in 36 trials involving targets A, B, C, and D made just one error. And in 50 trials involving targets 6 to 2 inclusive made only two errors. Subject T11 made two errors in 25 trials involving targets A, B, and C and one error in 40 trials involving targets 6 to 3 inclusive. There were other subjects in the trained group who made no errors on either targets C or B and three others who made no more than two errors in 40 trials involving targets 6 to 3 inclusive. In the untrained group subject U12 made no errors on targets A, B, and C; subject U8 made one error on these targets as also did subject U18. Subject U6 made two errors on A, B, and C total, and only one error in 40 trials involving targets 6 to 3 inclusive. Subject U12 also reached this latter criterion of 1 in 40. One subject in the trained group and five in the untrained appear to exhibit their mediocre ability in the test by making two or more errors in their five trials on target A. Since the populations of trials in each target for each subject did not exceed ten, it is not feasible to attempt giving individual thresholds for the subjects.

Both groups of subjects tended to give somewhat more responses in which they judged the bar to be "up" or vertical than "down", horizontal. The trained group showed 52.2% up and 47.8% down. The untrained group -- 50.7% up and 49.3% down. This predominance of judgments will be discussed later in this report.

Results for N and B Methods in Terms of Resolution Thresholds

The two methods of using binoculars may be further compared in terms of group target resolution thresholds achieved in the test. For this comparison we will group the results for all five stations, Table 3. Target A was exposed 115 times to each group of 23 subjects with 57 trials by B method and 58 trials by D method. This target was the largest and proved the easiest to see at well above the average threshold for each group of subjects. The trained subjects under condition B showed 92.6% correct resolution, and under condition N 91.8% correct. On target A the untrained subjects with B showed 82.2% correct, and for N 83.0% correct. For a population of 57 trials the 1% level of statistical confidence calls for a correct score of 67.7%. We may therefore conclude that target A was resolved by both groups with a relatively high degree of accuracy, but without showing assignificant difference between the two methods, B and N. In considering target B and including the remaining targets of both series, each target was presented to each group of 23 subjects a total of 230 times with approximately half (115) of the presentations by each method. With an N of 115 a percentage correct of 59.2 corresponds to the 5% level of confidence, and a percentage correct of 62.2 meets the 1% level of confidence. The score on target B for

TABLE 3

Responses of Trained and Untrained Subjects. Per cent Correct on Targets A through F and Targets 6 to 1 inclusive on All Stations Combined

		23 Trained Subjects				23 Untrained Subjects				Additional Untrained Subjects (Extra group of 6)(1A, 2A, 3A, 4A, 5A, 10A)		
Targets		B	Top B 2/3	N	Top N 2/3	B	Top B 2/3	N	Top N 2/3	B	N	B+N
Size (Largest in Series)	A	92.6	97.4	91.8	95.2	82.2	95.5	83.0	94.2	89.5	80.0	86.2
	B	75.5	81.3	81.6	88.6	76.7	86.6	71.9	79.5	77.2	85.2	82.2
	C	78.6	82.9	67.0	80.8	60.5	69.7	68.4	78.2	76.4	95.6	84.3
	D	48.8	52.6	63.9	70.6	45.1	52.3	52.1	55.4	75.0	54.8	64.4
	E	40.7	34.4	44.7	43.8	46.1	50.0	47.6	48.8	38.8	53.8	49.1
(Smallest)	F	41.5	39.1	39.7	41.8	46.9	47.4	37.3	39.8	36.6	48.2	42.1
Contrast	8									96.0	92.0	93.9
Contrast	7									93.1	94.7	93.8
(Greatest Contrast in Series)	6	81.0	89.5	73.9	82.1	75.8	82.7	71.4	82.0	93.7	96.0	94.7
Targets 6 to 1 inclusive	5	79.7	87.2	76.4	91.0	76.2	83.7	67.6	77.0	81.3	84.6	82.8
all B size	4	78.6	82.7	78.8	89.0	61.9	71.2	72.4	78.7	95.8	79.4	86.2
	3	75.0	77.6	68.4	81.8	64.8	74.7	69.9	73.3	84.6	85.6	85.1
	2	61.7	73.4	63.1	66.3	54.4	59.1	58.0	62.5	--	--	--
(Least Contrast)	1	57.2	55.2	58.6	58.3	51.9	50.0	56.7	58.1	--	--	--

trained subjects considerably exceeds this latter level with 75.5 for B method and 81.6 for N. The same is true for the untrained subjects on target B with 76.7 per cent for B and 71.9 per cent for N. With target C the trained group exceeded the 1% level showing, 78.6 per cent for B and 67.0% for N. However, the untrained subjects with the B method on this target (C) bearly exceed the 5% level (59.2) since they show 60.5% for B and achieve 68.4% for N. Therefore in the size series target C most nearly represents the threshold for the untrained group by both methods with the N method showing some advantage, while for targets D, E, and F they show no average value that equals the 5% level. The trained group reached their threshold with target D, and here also with the N method which shows 63.9% equalling the 1% level, whereas with the B method the percentage found is 48.8, indicating that for the B the threshold lies somewhere between C and D. It is interesting to note that targets E and F of the size series by both methods and for both groups show percentage right results that in place of being close to 50 are in the low 40's.

The contrast series of targets were as we know from previous discussion easier as a total group than the size series. They were all equal to target B (1. 2) in size, so that the white space between the bars was always the same for the entire set. Even though target 6, the strongest of the contrast series, had less contrast than target B, the results as shown in the table are substantially the same. The values for percentage right resolutions in the table tend to decline progressively from number 6 to number 1, where they still remain somewhat over 50%. The trained subjects reached their threshold value with target 2, where by the B method they showed 61. 7% and by the N method 63. 1%; the latter value reaches the 1% level of confidence, whereas the former falls about half-way between the 1% and the 5% levels. On target 1 the trained group did not quite reach the 5% level by either method but more closely approached it for N. The untrained group appear to reach their threshold at target 3 with 64. 8% for B, and 69. 9% for N. On target 2 they fall short of reaching the 5% level, but more closely approach it with the N method. Thus, it appears from these experiments that at or very near the threshold level for target size and for target contrast considered independently the results with the discontinuence use of the binoculars are better by about 1 target step in the series used. This difference in favor of the N method equals or exceeds the difference between a 1% level of confidence above chance and a 5% level. Table 4 gives results for the top 2/3, i. e., 16 subjects, for the trained and for the untrained groups and results on six additional untrained subjects. In the interest of brevity these results will not be discussed in the text.

General Threshold Levels for B + N Observations

If we combine the results for B and N methods the number of trials for each group on each target, with the exception of A, is theoretically 230 for all stations (see Tables 4, 5, 6 and 7). The 1% level of confidence is then 58. 6% and the 5% level 56. 5%. According to these standards the trained group with 55. 9% correct for target D falls slightly short from reaching the 5% criterion. The untrained group on target C with 64. 2% exceeds the 1% criterion but on target D shows 48. 7% correct. The threshold for size with high contrast falls between C and D for both groups, with the trained group closely approaching D. On the contrast series of targets the trained group almost succeeded in reaching the criterion for the 1% level with target no. 1, where the value found was 58. 2%, in place of the theoretical 58. 6. The untrained group came quite near meeting the 5% criterion on target 2 with 56. 2% correct in place of the required theoretical 56. 5.

Visual Resolution Thresholds With Reference to Distance

The five stations used for the targets varied in radial distance from the observer. From nearest to farthest station these were in order: Nos. 4, 2, 1, 3, and 5. Their relative distance in yards given in the same order were: 589, 927, 1162, 1697, 3830. The ratios of these distances are, taking the nearest as 1. 00: 1. 57, 1. 97, 2. 88, 6. 50. The total errors made by each group of subjects increased rather regularly from the nearest to the farthest station (see Tables 4, 5, 6 and 7). The increases in the errors expressed as ratios diverge widely from the distance ratios. For the trained subjects, taking the errors at the nearest station, no. 4, as 1. 00, the other stations in receding order are: 1. 11, 1. 24, 1. 33, 1. 61. For the untrained the ratios are: 1. 00, 1. 06, 1. 08, 1. 19, 1. 30. The trained subjects made more errors at all stations than did the trained group, the difference in general being more marked the nearer the station. Taking the number of errors made by the trained subjects at each station as a base, the untrained subjects at Station 4 made 25. 8% more errors, at Station 2 - 19. 2%, at Station 1 - 9. 0%, at Station 3 - 12. 9%, and at Station 5 - 1. 2% more than the trained subjects. The untrained subjects being poorer in general, their results did not suffer relatively so much with the increase in distance as did those of the trained group. In considering resolution thresholds attained at the five stations as individual stations our criterion values have to be based on 46 cases for each target

TABLE 4

Trained Subjects. Number of Trials, Errors, Right Responses and Per cent Right for Size and Contrast Targets by Stations, (N+B combined).

		Station 1				Station 2				Station 3			
Targets		No. Trials	E	Rt.	%Rt.	No. Trials	E	Rt.	%Rt.	No. Trials	E	Rt.	%Rt.
Size Series Largest	A	23	2	21	91.3	23	1	22	95.6	23	1	22	95.6
	B	46	12	34	73.9	45	6	39	86.6	46	11	35	76.1
	C	46	12	34	73.9	46	7	39	84.8	46	14	32	69.6
	D	46	23	23	50.0	46	18	28	60.9	46	19.5	26.5	57.6
	E	46	25	21	45.7	44	24	20	45.5	46	30.5	15.5	33.6
Smallest	F	46	31	15	32.6	46	27	19	41.3	46	29	17	37.0
Contrast Series Greatest	6	46	11	35	76.1	46	10	36	78.2	46	7	39	84.8
	5	46	10	36	78.2	46	9	37	80.4	46	8.5	37.5	81.6
	4	46	4	42	91.3	46	10	36	78.2	46	14	32	69.6
	3	46	11	35	76.1	46	10	36	78.2	46	14	32	69.6
	2	46	12	34	73.9	46	18	28	60.9	46	20	26	56.5
Lightest	1	46	22.5	23.5	51.1	46	17.5	28.5	62.0	46	18.5	27.5	60.0
Total:		526	174			526	157			529	183		
% Error:			33.1				29.9				35.1		
% Right:			66.9				70.1				64.9		

except for target A, which was 23 cases. The base of 46 calls for 69.8% right to reach the criterion of the 1% level of confidence and 64.8% for the 5% level. On Station 4, the nearest one, the trained subjects barely reached the 1% level with 69.5% correct for target D, while the untrained subjects for the same station with 67.4% for target C fall between the 1% and 5% levels. Results for the contrast targets and the trained subjects show target 2 a little short of the 1% level; the value found is 67.4%. The untrained subjects exceed the 1% level with target 3, but do not reach the 5% level with target 2. For Station 5, the most distant one, the trained subjects barely reach the 1% level with target B, showing 69.6%, while the untrained subjects at this station only succeed in reaching the criterion with target A. On the contrast targets for station 5 the trained subjects give results which seem quite irregular; they appeared to just about reach the 1% level with target 4, showing 69.6%. The untrained subjects at this station show uneven contrast results, but appear to meet the criterion for the 1% level with target 5.

TABLE 5

Trained Subjects. Number of Trials, Errors, Right Responses and Per cent right for Size and Contrast Targets by Stations, (N+B) combined).

		Station 4				Station 5				Total All Stations			
Targets		No. Trials	E	Rt.	%Rt.	No. Trials	E	Rt.	%Rt.	No. Trials	E	Rt.	%Rt.
Size Series Largest	A	23	1	22	95.6	23	4	19	82.6	115	9	106	92.2
	B	46	5	41	89.0	46	14	32	69.6	229	48	181	79.0
	C	46	12	34	73.8	46	18	28	60.8	230	63	167	72.6
	D	46	14	32	69.6	46	27	19	41.3	230	101	128.5	55.8
	E	46	24	22	47.8	46	27.5	18.5	40.2	228	131	97	42.5
Smallest	F	46	21.5	24.5	53.2	46	28	18	39.2	230	136.5	93.5	40.7
Contrast Series Greatest	6	46	5	41	89.2	46	20	26	56.5	230	53	177	77.0
	5	46	7	39	84.8	46	16	30	65.2	230	50	179.5	78.0
	4	46	7	39	84.8	46	14	32	69.6	230	49	181	78.7
	3	46	9	37	80.4	46	20	26	56.5	230	64	166	72.2
	2	46	15	31	67.4	46	21.5	24.5	53.3	230	86	143.5	62.4
Lightest	1	46	20.5	25.5	55.8	46	18	28	60.8	230	97	133	57.7
Total:		525	139			525	226			2622	879		
% Error:			26.5				43.0				33.5		
% Right:			73.5				57.0				66.5		

We have seen that the performance on the nearest Station no. 4, with the trained subjects was two target steps lower in the size series (1.68), that is, target D, as compared to target B (1.2) on the most distant station, no. 5. For the intermediate stations, nos. 2, 1, and 3, in order of distance from the observer, the trained subjects show the same trend in their results. At all three of these stations they reached or exceeded the 1% criterion on target C (1.41). At Station 2 they had 84.8% correct, at Station 1 - 73.9% correct, and at Station 3 they amost equalled the 1% criterion - 69.6%, in place of the required 69.8. The same trend is observed in the results for the untrained subjects on the intermediate stations. On Station no. 4 with 67.4% on target C their performance falls between the 1 and the 5% criteria, while for Station 5 their results are essentially two target steps poorer, meeting the 1% criterion for target A with 78.3% correct. For the remaining stations, nos. 2, 1, and 3, they reached the 1% criterion for target C with Station 2 and were slightly above the 5% criterion on this target for station 1 and 3, with 65.2% on each of them. On

TABLE 6

Untrained Subjects. Number of Trials, Errors, Right Responses and Per cent Right for Size and Contrast Targets by Stations, (N+B combined).

	Station 1				Station 2				Station 3			
Targets	No. Trials	E	Rt.	% Rt.	No. Trials	E	Rt.	%Rt.	No. Trials	E	Rt.	%Rt.
Size Series												
Largest A	23	4	19	82.6	23	3	20	87.0	23	5	18	78.3
B	46	12	34	73.9	46	10	36	78.2	46	10	36	78.2
C	46	16	30	65.2	46	14	32	69.6	46	16	30	65.2
D	46	28	18	39.1	46	23	23	50.0	46	24	22	47.8
E	46	21	25	54.3	46	26	20	43.5	46	26.5	19.5	42.4
Smallest F	46	27	19	41.3	46	27	19	41.3	46	26	20	43.5
Contrast Series												
Greatest 6	46	10	36	78.2	46	12	34	73.9	46	11	35	76.0
5	46	13	33	71.7	46	12	34	73.9	46	17	29	63.0
4	46	14	32	69.6	46	14	32	69.6	46	12.5	33.5	72.8
3	46	12	34	73.9	46	15	31	67.4	46	15	31	67.4
2	42	17	25	59.5	42	12	30	71.4	42	24.5	17.5	41.7
Least 1	42	16	26	61.9	42	20	22	52.4	42	23.5	18.5	44.1
Total:	521	190			521	188			521	208		
% Error:		36.7				36.1				40.4		
% Right:		63.3				63.9				59.6		

the contrast series the influence of distance shows the same trend with both groups of subjects as found for the size series. On station 4 the trained group succeeded better than the 5% level with target 2 for station 4, while suffering a loss of two target steps, just barely meeting the 1% criterion for target 4 on station 5. There was a reversal of the results for stations 1 and 2; on 2 the 1% level was exceeded on target 3 with 78.2% and on station 1, the 1% level was exceeded with target 2 with 73.9%. However, station 3, the most distant of this group, showed the poorest results, just meeting the 1% level on target 3 - 69.6%. The untrained subjects on station 4 with the contrast targets exceeded the 1% level with target 3 - 74.5% and just barely reached the 1% level with target 5 on station 5 showing 69.6%. For the stations of intermediate distance they show their best results on station 2 with target 2 at 71.4%; then comes station 1 with target 3 - 73.9%, and finally, station 3, the more distant of these, target 3, with 67.4% falling between the 1 and 5% criterion.

TABLE 7

Untrained Subjects. Number of Trials, Errors, Right Responses and Per cent Right for Size and Contrast Targets by Stations, (N+B combined).

Targets		Station 4				Station 5				Total All Stations			
		No. Trials	E	Rt.	%Rt.	No. Trials	E	Rt.	%Rt.	No. Trials	E	Rt.	%Rt.
Size Series													
Largest	A	23	3	20	87.0	23	5	18	78.3	115	20	95	82.6
	B	46	9	37	80.4	46	18	28	60.9	230	59	171	74.4
	C	46	15	31	67.4	46	21.5	24.5	53.3	230	82.5	147.5	64.1
	D	46	19	27	58.7	46	24	22	47.8	230	118	112	48.7
	E	46	23.5	22.5	48.8	46	25	21	45.7	230	122	108	46.9
Smallest	F	46	27	19	41.3	46	26.5	19.5	42.4	230	133.5	96.5	42.0
Contrast Series													
Greatest	6	46	9	37	80.4	45	18	27	60.0	229	60	169	73.8
	5	46	8	38	82.6	46	14	32	69.6	230	64	166	72.2
	4	46	17	29	63.0	46	17	29	63.0	230	74.5	155.5	67.7
	3	47	12	35	74.5	46	21	25	54.3	231	75	156	67.5
	2	41	16	25	61.0	42	22	20	47.6	209	91.5	117.5	56.2
Least	1	42	19	23	54.8	42	17.5	24.5	58.3	210	96	114	54.3
Total:		518	176			517	228			2592	990		
% Error:			34.0				44.4				38.3		
% Right:			66.0				55.6				61.7		

Station 5 while being the most distant from the observer also required him to turn from the pre-fixation point through the largest angle, which was 19.5 degrees. This station shows also decidedly the largest number of errors. But it appears fairly clearly that the factor which tends to increase the errors is the linear distance of the target from the observer rather than the angular turn that he has to make to reach the target. The latter, as we have seen, tends to influence somewhat the duration of the "on" time and of the response time. If we consider station 4 as a base for computation, this may be compared with station 1, which required about an equal angular turn, 16.5 degrees to the left as compared to 15.5 degrees to the right. The trained group made 24% more errors on station 1 than on station 4, and the untrained group 8% more errors. But the comparative distance of station 1 to station 4 is approximately 2 to 1. Again, station 2 which requires only a 5 degree turn but is 1.57 times farther away than station 4 produces for the trained subjects 11% more errors, and for the untrained 6% more errors. Station 3 which requires the smallest turn, 1.5 degrees and is 2.88 times as far away as station 4, produces for the trained 33% excess errors and for the untrained 19%. It may therefore be assumed that the

different stations as angular locations about the subject were not favored in accuracy of resolution response in terms of their nearness to the pre-fixation point, but did vary in visibility due to atmospheric haze according to their distance from the observer. The influence of the haze on the accuracy of observations in these experiments is not in direct ratio to the distance but more nearly coincides with the logarithm of the distance.

N and B Methods Compared In Data For Combined Groups

The B and N methods may be examined by grouping together all of the data for the 23 trained and the 23 untrained subjects (Table 8). In this combined grouping we have counted only the instances where a definite judgment was made omitting those trials when the subject was indefinite and gave a question mark. The number of trials for each target by each method, except target A, was therefore close to 230, sometimes slightly above and other times below this figure. On this basis the per cent right answers which represents a

TABLE 8

Resolution Threshold Results for Trained and Untrained Groups Combined (46 men), Comparing Methods B and N. For All Five Stations.

	Method B			Method N			
Targets	No. of Trials	No. Right	Percent Right	No. of Trials	No. Right	Percent Right	N - B
A	116	101	87.0	114	100	87.8	+ .8%
B	214	163	76.2	246	190	77.2	+1.0%
C	236	163	69.0	224	151.5	67.6	-1.4%
D	235	110.5	47.0	225	130	57.8	+10.8%
E	227	98	43.2	231	107	46.3	+3.1%
F	235	103.5	44.0	225	86.5	38.5	-5.5%
6	224	175	78.1	235	171	72.8	-5.3%
5	233	181.5	77.8	227	164	72.2	-5.6%
4	222	157	70.6	238	179.5	75.4	+4.8%
3	240	169	70.4	221	153	69.2	-1.2%
2	210	122	58.1	228	138.5	60.7	+2.6%
1	225	123	54.6	215	124	57.6	+3.0%

probability value for the 1% level of confidence is 58. 6% and for the 5% level 56. 5%. The combined group of 46 subjects far exceeded the 1 per cent level for targets A, B and C for both methods, B and N, as shown in Table 8. On target D with the N method the 46 men exceeded the 5% level but did not reach the 1% level with a showing of 57. 8% correct while with the B method they showed 47. 0% correct, the difference of 10. 8% in favor of N method is the outstanding difference between N and B shown for the size series and, as we know, this occurs at a level of seeing difficulty that approximates the group threshold. In the contrast series numbers 6, 5, 4 and 3 show average results for both methods that are all 70% or better with exception of target 3 by the N method which was 69. 2% correct. These values are all well above the 1 per cent level of confidence and in only one of the four, that is number 4, did the N method seem to give higher results. For the other three targets B was higher by 1. 2 to 5. 6%. For contrast target 2 by the B method the 46 men show 58. 1% and by the N method 60. 7%. The former value well exceeds the 5 per cent level of confidence, the latter value exceeds the 1 per cent level of confidence. On contrast target 1 by the B method, 54. 6% does not reach the 5 per cent level but 57. 6% by the N method reaches and somewhat exceeds the 5 per cent level. Again we find that near the threshold, this time with the contrast series of targets, the N method appears to be slightly superior by about 3% more correct resolutions, a difference that is a little larger than the step between the 5 per cent and 1 per cent levels of confidence.

In these experiments with binoculars subjects attempting to resolve the two bar target in reference to its orientation, were not rewarded for being either quick or accurate. At the time of giving the test the experimenter and his staff did not know whether the subject's responses were correct or incorrect. Only the subject was in a position to form a judgment on the basis of his own subjective confidence after checking his impressions received from viewing the target.

Haze Measurements

The haze measurements taken on the roof of the Institute of Human Relations were made using a miltiplier phototube corrected to fit the eye characteristics and to measure the relative contrast between the rock faces of East Rock and West Rock and the sky immediately above them. While it is admitted that these are not standard devices and that the brightness of rocks is subject to the angle of the sun in the sky and the amount of overcast the measure obtained gives an estimate of atmospheric transmission. These estimates correlate roughly with the estimates of visibility made by the United States Weather Bureau in East Haven. It should be emphasized however that the Weather Bureau visual estimates are limited by virtue of their physical location to a maximum direct estimate of two miles meterological range because the most distant target visible from their observation station is two miles away. The visibility estimates of the Weather Bureau then are based in terms of their judgment of the visibility of their two mile objects. The correlation between two sets of estimates -- Weather Bureau and our own -- will further be limited by virtue of the presence of city heat over the optical range. Visibility because of this heat would always be expected to be greater than that over an optical range of lower earth temperature. The best correlational estimates to make are those between the photo-electric hazemeters and our half-black photographs of the target squares at each of the target locations.

This problem of haze and resolution thresholds is not fundamentally involved in the subject title of the present paper and therefore not treated here. It is anticipated that a discussion of it will be presented elsewhere.

Deviation From Chance in Judgments

The judgment of vertical or "up" which slightly predominates over the judgment of

"down" for both groups of subjects seems to show itself particularly on targets D, E, and F of the size series. When all the trials on these three targets are grouped together we find that the trained subjects with targets presented with the bars vertical achieved 52.5% correct responses and with the target bars horizontal got only 40.1% correct. The untrained group with the bars vertical got 48.0% correct and with the bars horizontal 44.3%. The untrained group showed a somewhat similar effect for the three most difficult of the contrast targets, that is, targets 3, 2 and 1. Grouped together, for the vertical bars their score was 61.6% correct and for the horizontal bars 57.6%. The trained group showed this same tendancy on targets 3 and 1 but not on 2 so that their average for the three targets taken together is for bars vertical 62.4% and for bars horizontal 65.0%. The tendency is slightly more marked with the N method than with the B method for both groups. Our supposition is that the effect is due to tremor. If the principal displacement from is a vertical one in hand-held binoculars as seems probable, then it might be assumed that vertical target bars would be a little more visible than horizontal ones and the latter would more frequently be misjudged.

It seems just possible that some relation to this judgment tendency may be found in the stance of the subject. Both groups of subjects had a preponderance of "down" responses for stations 1, 4 and 5 and a preponderance of "up" responses for stations 2 and 3. For this parallel tendency in both groups which is not a marked one even though exhibited with fair regularity, we have no explanation other than that it may be related to the subjects' stance. In turning from center to right or left the subjects did not move their feet and hence for stations 1, 4 and 5 had postures that were more twisted than for 2 and 3.

General Discussion

The visual task outlined for examination in the introduction to this paper represents a very special case or kind of lookout scanning. In actual military practice the observer does not know just where or when to look with the expectation of seeing critical objects nor does he know precisely what type of target may appear. In the present study the observer did not know which of the twelve targets might appear at a given time in the routine, but he did know where some one of this limited number, all of them bar-targets, would be exposed to his view. And after he had responded to that challenge he had no immediate observer responsibility until another station was called. This is a very different situation from being on watch duty. However, the two methods of using binoculars compared in this study are basically those employed by military lookouts and in this sense our results may be considered as fundamentally concerned with lookout technique and practice.

The data collected support the conclusion that the continuous and discontinuous methods of using binoculars (B and N techniques, as described and used here) do not yield equivalent results either in speed or in resolution accuracy of performance. Within the limits of our experimental conditions the use of the binoculars only at the time of looking at the target areas, after having located them by naked eye, is slower but yields a somewhat better resolution threshold in most instances than to use the glasses all the time (B method). Choice between the two methods in a practical situation would seem to rest on the judgment of the relative importance of speed vs. threshold detection.

In the free and easy atmosphere of our "no-danger" test situation 12 of the 23 Navy subjects expressed a preference for the N method, 9 preferred the B and 2 had no preference. Among the untrained subjects 7 "voted" for N, 13 for B, and 3 had no preference. It seems probable that the men who had less practice in the use of binoculars would tend to prefer keeping them at their eyes rather than making the numerous ocular adjustments that the N method required.

The size of our subject samples (23 men in each group) while not as large as might

be desired seems to have been adequate and we believe representative for usual military personnel in service or at time of drafting. It was found as expected that the trained group did somewhat better than the control group. But this difference proved smaller than anticipated. We found it impractical to attempt correlating our individual results for the Navy men with officer ratings on their excellence as lookouts -- routine non-combat service provides relatively little on which such ratings can be based.

Search of the unclassified literature has revealed very little in the way of studies with which the results of this investigation may profitably be compared and criticised. The two-bar square acuity target is not in popular use. It was recently illustrated by Chapanis (2), (see his Fig. 16, p. 26) but was included in the highly important survey-analysis of numerous types of acuity objects reported on from The Adjutant General's Office in 1948. The research group of 1920 composed of Hyde, Cobb, Johnson and Weniger (3) in a study of the relative merits of monocular and binocular field glasses used as test-object "a white square with a black strip running through it symmetrically and equal in area to one-third of the square." This target presenting two white bars could be varied in size from 36 inches on each side down to zero. "The object was presented against a black background; its size was varied and the position of the strip was changed from vertical to horizontal in a helter-skelter order." The observers used a 6X25 Leitz binocular at a distance somewhat more than one-half mile away from the target. The actual distance in yards is not given nor are the target dimensions stated that corresponded to different percentages of right resolution responses. For the purpose of comparing field glasses the experiment with data for some 1200 observations for each of three well trained subjects was excellent. Our results where comparable tend to agree, for example, both studies show that relatively large stimuli gave short resolution times; that when both right and indeterminate judgments appear the time required is larger for the latter than for the former. Unfortunately from this older study we are not able to determine a factor of efficiency for the binoculars that were used.

Summary

1. The speed and accuracy of locating and resolving two-bar (black on white) targets at five fixed field stations varying in distance from about 1/3 to 2 miles were studied by the use of 7X50 binoculars employed according to two methods: N, glasses used at the target only after the station position was located by naked eye, and B, glasses used all the time in locating and in examining the target.

2. Two groups of men were used as subjects: 23 from the U. S. Submarine Base at New London who had had lookout experience on submarines were designated as Trained Group, and a Control Group of 23 young men from the New Haven area matched for age, education and eyesight qualification with the Navy subjects. Age range was 18 to 26 and the visual requirement 20/20 or better.

3. The five target stations were distributed over a lateral sector of 36 degrees with station No. 1 at the extreme left and station No. 5 at the extreme right of the sector. About midway on the horizon a tall tower served as pre-fixation position before each station was called by the experimenter.

4. Two sets of six targets each were prepared in appropriate size for each station according to its distance and on the assumption that 7X50 binoculars with coated lenses would yield a realized efficiency factor of 4.48X or 64%. Target set A to F varied in size of the critical detail from 60 sec. of arc, in logarithmic steps to 25.2 sec. Target set 6 to 1 was all of size B but varied in contrast: for No. 6 the bars had a luminous reflectance of 12 per cent and for No. 1 of about 79 per cent.

5. The two methods, the five stations and the twelve targets were all randomized for each

subject separately. Each subject was given pre-training and served individually for one hour plus making 115 response judgments of whether the target bars in each presentation at each station were vertical or horizontal. According to plans each would provide 2645 test judgments -- the Navy group made 2641 and the Control group 2644. About half the tests in each total were by method N and half by B.

6. As an over-all comparison the Navy group in 1319 B tests gave 67.0% correct responses and in 1322 N tests gave 67.0% correct. The Control group in 1299 B tests had 61.4% rights, and in 1305 N tests 61.7% rights.

7. The time requirements (2.33 to 2.75 sec.) to shift from the pre-fixation position to the target area called was longer for N than for B method by 0.16 sec. for the trained group and by 0.30 sec. for the Control group. These differences in favor of B as the more prompt method reach the criterion of the 1 per cent level of confidence.

8. The time elapsing from signal to resolution response (about 4.70 to 6.50 sec.) was dependably (better than 1 per cent level) shorter for the B method.

9. For the size series of targets the Navy group reached their threshold by the N method on target D, (35.7 sec. of arc) and by B method between C and D, (42.4 and 35.7 sec.). Target C most nearly represents the threshold for the Control group by both methods with the N method showing some advantage. The N method therefore proves superior to B in terms of threshold resolution while B on the average provides the quicker performance.

10. Both these methods of using hand-held binoculars are basic in watch duty and lookout practice. Which one should be used in a practical situation evidently depends on the nature of the anticipated hazards.

11. The assumption of an efficiency of 64% for 7X50 binoculars with coated lenses appears to have been vindicated in this study. If the resolution of 60 sec. targets were taken as the optimal criterion an efficiency factor somewhat higher than 4.48X is clearly indicated by our threshold results.

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SURVEY OF COCKPIT VISUAL WARNING SYSTEMS

By Fred R. Brown, Marion P. Willis,
and Lloyd M. Crumley

A Navy pilot with whom our Vision Section has occasion to discuss problems of cockpit visual displays offered this comment: "People think that flying these jet airplanes is harder than it really is. They don't realize how much of the stuff in the cockpit we ignore".

This seems to indicate that in flying, as in the daily activities of all of us, we exercise some skill in ignoring what in our judgment are the less important aspects of the informational media available to us. This ability plays a significant role in enabling us to make adequate use of those informational presentations which do have important bearing on the task at hand.

Our pilot friend has pointed out that he is perfectly willing to concentrate his attention upon those instrumental and control presentations which, in his opinion, have the greatest importance for the pursuit of his flying activities. It is fortunate that this tendency to ignore the momentarily trivial and concentrate on the immediately essential exists. It is an especially desirable frame of mind to carry into the modern military aircraft cockpit where increased aircraft performance has resulted in a greatly decreased amount of time available for the pilot to consider his course of action. Coupled with this is the increased complexity of the information available. Decisions must be made and, in order that they be made wisely, pertinent information must be furnished in such a manner that the operator is relieved of the burden of separating the material of consequence from the routine information. Realization that the pilot does not have time to consider all information and still safely react to all routine flight situations has resulted in the design of cockpits making it possible for the operator to consider only the displays that are of immediate value and, relatively speaking, to ignore all the others. It is common practice, for example, to provide cockpit illumination systems with controls to maintain large portions of the cockpit in darkness. Not only can the console control arrays be in darkness and, therefore, be effectively ignored, but instrument panels themselves have an appreciable number of dials, the so-called non-flight instruments, which can be darkened and disregarded when the pilot deems them unimportant.

Our pilot friend could not deny, however, that, much as he would like to ignore certain kinds of information about his aircraft, at a certain stage of his task such ignorance could lead to tragic errors. Similarly, even those elements to which he is attending can reach dangerous levels which he may not readily realize. It becomes a basic need, therefore, to provide means by which visual display elements can be effectively ignored when no significance attaches to the element in the current flying task but which cannot be ignored at the time when it becomes vital. Similarly, effective means must be found to make significant meanings of displays evident even when the data on which they are based are not being totally ignored, and to present other items in such a way that they remain constantly at some attention-commanding level despite the pilot's desire to ignore them.

This need in cockpit design leads to the development and utilization of special attention devices. These devices serve the purpose of raising some piece of presented information above the attention-getting level of the remainder of the display either constantly or for a short time when needed. The display may be presented to the visual, the auditory, the kinesthetic, the cutaneous, or even, as some have suggested, the olfactory modality. All these forms of display lend themselves to presenting a single item of information or a group of items with special attentior-getting characteristics. This paper is concerned exclusively with the present status of cockpit visual attention devices.

This subject has received greatly increased emphasis recently on very practical levels.

Two recent Navy fighter aircraft in which eighteen so-called warning lights are to be found in the cockpit may be cited as illustrations of the urgency of the problem. We find very little delineation of the true warning items in these aircraft. Furthermore, there is a variety of colors, unstandardized coding, placement that is logically but not psychologically correct, inappropriate methods of identification, and poor provision for the control of the intensity for the several conditions of use.

On the practical level, the Cockpit Layout Panel, an Air Force-Navy group under the auspices of the Munitions Board, has been trying over many months to reach policy decisions on the use of special attention devices. I can report to you that progress has been made. At the Nineteenth meeting an agreement was reached on the definition of a warning light. Warning lights were defined as "those lights indicating that a condition exists which might result in the loss of an aircraft unless immediate corrective action is taken".

In approaching the design of suitable devices keyed to the level of attention-getting power desired, it is necessary to be fully aware of the psychological principles applying to the subject of attention. Regardless of the several theoretical orientations held by writers in this field, the literature indicates agreement upon several attributes which will cause an element of the visual display to stand out as a figure, with the remainder of the display appearing as background. These attributes affecting attractibility have been catalogued to include size, shape, brightness, hue, saturation, motion, location in the visual field, sharpness of contour, and continuous or intermittent presentation. Variability in these attributes exists within most useful displays in which several elements are competing for attention. The element which wins the competition, however, is the one which stands highest on a quantitative scaling of the attributes or which varies recognizably from the balance of the display in some manner. For example, on the currently used aeronautical trans-illuminated plastic control panels, it is good practice for visual effectiveness to maintain uniform size of lettering, preferably 9/64" in height. However, for the few legends or titles which are used for panel identification or to call attention to a particularly important item, lettering only 1/32" larger than the remainder makes these legends distinctive.

In addition to the stimulus variables which influence attention, the mental set and the capacity of the observer affect the organization of the visual field. In general, only a single element, or a single group of elements composed of somewhat less than a dozen units, can have clarity for the observer at a given time. However, certain patterns in a complex visual field can extend this range. In addition, the observer is capable of rapid fluctuations from one item to another, which increases the apparent span of attention. Furthermore, the attitude of the observer is significant in determining how much distraction is needed for a given special attention device and how much detailed instruction for action is needed. It appears that, in general, it is not necessary to spell out in detail courses of action on these devices. A readily understood phrasing of the dangerous condition is sufficient. Another attitudinal factor that should be mentioned is the pilot's confidence that he can pursue his duties with full reliance upon the fact that he will be sharply informed of some serious condition such as engine fire. This confidence enables him to devote himself to his tasks with minimized concern for the low probability eventualities.

Our group has been concerned with four general classes of special attention devices. The first of these includes range markings. These markings are applied to the cover glass of aircraft instruments to indicate such things as the maximum or minimum save reading, the normal operating range, test points, etc. Formerly, with white incandescent or ultraviolet lighting, colored reflective material or fluorescent paints and decals of varying form were satisfactory. With color coding eliminated by the use of red lighting in cockpits, more attention has to be paid to other attention-getting factors for night use, although color can still be effective for day use. Greater attention is being given to reflective properties and shape and size factors for these markings. At present, we are recommending wide-stroked, colored, bracket-shaped marks which are colored red for day attention attraction and which, because they are closer to the lamps than are the dial markings, are bright reflecting for night use. The use of multi-faceted reflectors is under consideration also.

Another category of special attention devices may be called placards or special attention plates. These are legends which supply the pilot with information he should know but which is considered important enough to warrant constant display with some attention-demanding qualities. Typical is the legend: "WARNING - DO NOT LOWER FLAPS ABOVE 220 KNOTS". Here the problem is to attract attention without excessive glare or disturbance. Using the current plastic plate lighting techniques, our laboratory conducted preference and legibility tests utilizing the specification form for these markings and several alternate forms. The results indicated that a trans-illuminated design composed of narrow lines pointing out the legend was adequate for night. For day, a superimposed red border is needed while the immediate surround of the legend is black. The currently specified design was the least satisfactory of those tested. Check-off lists, reminders of proper actions and the special situations in which they apply do not need the border of trans-illuminated lines and color. They are usually directly in front of the pilot, are consulted only under specific circumstances, and can even be unlighted until needed.

Indicators of the current status of operational factors which fall outside the criteria for warning lights, are the third class of special attention devices. They must be clear and distinct as to meaning, but are not meant to be distracting in effect. The attempt to satisfy this requirement with the usual warning lights results in confusion of meaning and, indeed, in loss of effectiveness of the true warning light. Some schemes attempt to provide indicator lights which are yellow and warning lights which are red. In distraction effectiveness, the yellow may be better, which is just the reverse of the desired situation. As a result of this undesirable confusion, we are attempting to develop and apply other types of "yes-no" indicators which are not dependent upon light alone. Among the devices is a magnetic "flip-flop" indicator which presents a changed visual indication without auxiliary lighting. Another type is a trans-illuminated legend which, although incorporating a light, is distinctly different in size, brightness, location, and flashing characteristics from the cockpit's warning lights.

Finally, there are those indications which comply with the requirements for proper application of a warning light. In the past, the major problem with these warning devices has been their lack of clarity as to meaning and the insufficiency of their distractibility. Suggestions made for improved warning light systems include an explanatory legend which lights with the warning light, a trans-illuminated legend standing alone, use of a master warning light, central grouping of warnings, location coding techniques, projected warnings, and the use of a flashing presentation. Our laboratory has made a number of recommendations with respect to warning lights. First, it appears necessary that an adequate explanatory legend or pictorial display be used and it seems preferable that the legend itself should provide the distracting effect. Secondly, there seems to be no reason for using a confusing color coding system. Red appears to be adequate. It also seems desirable to have a flashing presentation combined with relatively large sized letters of proper brightness in order to provide satisfactory attention-getting qualities. Studies now under way are meant to determine the relative brightness required under the varying day and night operating conditions, the proper flash rate, and the proper size of lettering and other markings. If automatic dimming for night can be dispensed with, a considerable weight saving, always desirable in aircraft design, will result. Among the devices which our laboratory has proposed or studied is a flush mounted warning in which the filaments are viewed from the side. The use of two lamps adds an important safety feature. Another form of warning display involves the use of the rear view mirror found in many aircraft. In this device, the mirror is half-coated and a rear light and legend provides the warning display. This technique allows placing the display directly in front of the pilot, which appears to be the preferred location. The flush type warning device can also be mounted above the instrument panel or on the windscreen framing, providing eye-level locations for the fixtures.

Projection techniques for placing warnings on a reflection screen on the windscreen framing or directly on the windscreen have also been investigated. While such methods

yield interesting displays, it is not believed that such elaborate techniques are required for an adequate warning method.

The use of a master warning located in a position that will provide for maximum attention-getting and an auxilliary device located near the specified item or required control appears to be a promising possibility.

The techniques discussed here under the several groupings of special attention devices show the efforts currently being made to insure that our pilot friend in the future will be able to ignore some of the "stuff" in the cockpit, but that the more important will be forced upon his attention when and as he needs them.

Discussion:

Dr. Kenneth Brown stated his belief that what is needed is a master warning device which is activated whenever anything is wrong and a panel of warning devices to tell the pilot specifically what is wrong.

Mr. Brown stated that in his opinion a system involving specific warnings for specific difficulties was equally good. This is because the warning devices are located in special proximity to one another and any warning has about as much attention-getting value as any other.

Dr. Beck asked whether the possibility of using a complicated temporal sequence of auditory tones could be employed such that any mal-functioning in the aircraft would be revealed by a change in the patterning of the auditory signals. The basic principle is that the human is very sensitive to meaningful sequences of sensory signals and any departure from the standard sequence is very quickly appreciated.

Col. Byrnes asked if Dr. Beck meant that there would be a constant auditory "racket" in the ears of the pilot.

Dr. Beck stated that he meant to suggest that a melody could be employed such that if anything went wrong with the aircraft, the melody would be distorted.

Dr. Davis stated that the basic principle Dr. Beck was proposing had been tested by the Special Devices Center. It was first tried to warn the pilot as to whether or not the landing gear was in readiness. The device was not very successful because of control tower noise. A similar principle was employed in connection with check-off lists employed by pilots before taking off or landing. It was found that pilots do not read check-off lists. In order to get them to complete their check-off, each item on the check-off list was made to correspond to a segment of a circle of light. Only when each individual item had been checked could the pilot get a completed circle of light indicating that all was in readiness for landing or take-off. Most of the pilots liked the system. This method is still being worked on by Special Devices Center and has not been officially reported as yet.

Dr. Miles suggested that the use of an aperiodic auditory signal would be very effective as a warning device.

Mr. Brown stated that aperiodic stimuli have been tried and that the best ratio between on and off seems to be about 2-1.

Dr. Davis stated that flashing rate and intensity of visual warning devices had been studied by the Special Devices Center.

Dr. Orlansky stated that in his opinion it is necessary to resist trying to be ingenious in designing warning devices. He stated that in his opinion it is necessary to think of the poor pilot who has to use the device. The biggest problem is the problem of evaluating the effectiveness of the device. Dr. Orlansky stated his opinion that methodological studies should be the next step.

Mr. Brown agreed that systems evaluation should be employed in any warning system.

THE EFFECTS OF PURE RED AND LOW COLOR TEMPERATURE WHITE INSTRUMENT LIGHTING UPON DARK ADAPTED VISUAL THRESHOLDS

Kenneth T. Brown
and
Walter F. Grether

INTRODUCTION

The Air Force currently specifies both red and white lighting systems for illuminating aircraft instruments, as established by Specification MIL-L-6423 (USAF). The pilot has an indirect red system which is augmented by a red flood system and both of these are for use at low intensity under conditions demanding dark adaptation. On the other hand, high intensity white flood lighting is also provided to attain adequate visibility of aircraft instruments during thunderstorm flying, during high altitude daytime flight, or during simulated instrument flight with the amber hood and blue goggles. When the intensity of white light is reduced by means of a rheostat, the color temperature of the light decreases and it becomes reddish in appearance. This raises the question of whether low color temperature white light is significantly inferior to pure red light for maintaining dark adaptation. If not, it may be possible to use a single white lighting system both for high intensity lighting and as an auxiliary system under conditions demanding dark adaptation. Crew members such as the navigator, bombardier, radar operator, radio operator, E C M operator, and engineer are now provided with both white flood and red flood lighting systems. If low color temperature white light is satisfactory from the standpoint of dark adaptation, however, it may be advisable to use it instead of red flood lighting at these positions.

Red lighting has become standard for conditions demanding dark adaptation because preadaptation to red light permits more rapid dark adaptation than preadaptation to white light of equal photopic brightness. This has been adequately demonstrated by Rowland and Sloan (5), as well as others. The studies along these lines have been reviewed by Kappauf (3). These studies prove that red light is better than white light for ready rooms and other lighting situations, after which most rapid dark adaptation is desired. However, the advantage of red light over low color temperature white light for maintaining dark adaptation during instrument reading has not been determined. It seemed desirable to make this comparison under the lighting conditions which pertain in the cockpit, especially with regard to the brightness levels employed and the use of a simulated instrument panel. The present experiment was undertaken, therefore, with this as the major purpose. It was also desired to evaluate the red flood lighting system which is currently used from the standpoint of effect upon dark adaptation.

APPARATUS AND SUBJECTS

Apparatus:

A lighting apparatus was fabricated for presenting the various lighting conditions, and a Hecht Shlaer Adaptometer was used for measuring visual thresholds. The lighting apparatus is shown in Figure 1. It consisted basically of a plywood box, the inside of which was 21 in. high, 28 in. wide, and 18-1/2 in. deep. A chin rest was mounted on the front of the apparatus to steady the subject's head and to maintain a 28 in. viewing distance. A simulated instrument panel was mounted on the back of the box. In making this panel, the faces of actual aircraft instruments were mounted on a sheet of plywood. The instrument faces were the standard type consisting of fluorescent markings on a black background. The arrangement of instrument faces did not conform with the actual arrangement in the cockpit, but the spacing conformed with spacing in the cockpit. The area of the instrument panel

which was actually covered with instruments was 19 in. long and 10 in. high. The background of the simulated instrument panel, as well as the entire plywood box, was painted with flat black paint. A solid white viewing panel was also used. This panel was made of

Figure 1. Lighting Apparatus

Crescent Illustration Board No. 100, and a slot was provided which permitted the white panel to be inserted directly in front of the instrument panel.

The instrument panel was used to provide a close approximation to the adaptation conditions encountered in flight. The white panel was provided for three reasons. First, it was possible to use a fixation point with the white panel but this was not desirable with the instrument panel. Thus with the white panel it was possible to obtain better control of the brightness of the adapting stimulus. Second, since the instrument panel consisted of discrete instrument markings on a black background, the solid white panel was expected to produce a greater effect upon dark adaptation. Hence the white panel was expected to provide a more rigorous test of the relative effects of pure red and low color temperature white lighting upon dark adaptation. Third, it was desired to compare the loss of dark adaptation with these two kinds of preadaptation stimulus areas.

The viewing panels were illuminated with eight A-11 Grimes cockpit lights, the standard type for red flood instrument lighting. Four lights were mounted above the viewing

panels and four were mounted below. The distance between the lights and the viewing panels was 15 in. The frames holding the red filters over the lights were removed and the filters were cemented in the frames. This made it possible to slip the filters over the lighting units to provide standard red flood light, or the filters could be removed to provide low color temperature white light. The purity of the red light is indicated by Figure 2, which shows the per cent transmission curve for the red filter. It proved impossible to measure the color temperature of the white light because all the color temperatures used in this study were too low to be measured by the Eastman Color Temperature Meter. This means all color temperatures were below 2000° K. and the white lighting was distinctly reddish in color.

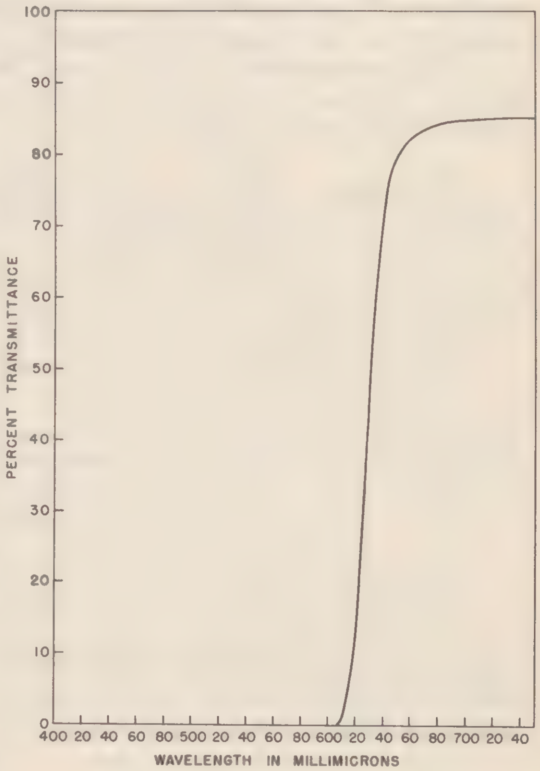

Figure 2. Percent transmittance curve for red filter in Grimes A-11 Lighting Units.

The current for the lighting units was obtained from a 110 V. 60 cycle source with a constant voltage transformer for voltage stabilization and a Variac transformer for voltage adjustment. A third transformer reduced the maximum of 110 V. to the maximum 28 V. rating of the lamps. A voltmeter was attached to the secondary of the 28 V. Transformer in order to measure the actual voltage across the lamps.

The Hecht-Shlaer Adaptometer was placed to the left of the lighting apparatus. Thus after looking at one of the viewing panels under one of the lighting conditions, the subject turned 90° to his left and was in position for making threshold measurements. Thresholds were measured with a white test patch 3° in diameter, which was viewed 7° left of the fixation point in the right eye. The exposure time was 1/5 sec. This is the standard procedure for threshold measurements recommended by Hecht and Shlaer (2).

Subjects:

Six subjects were used in this experiment, all of whom were male employees of the Aero Medical Laboratory. The age range was from 25 to 36 years. Three subjects were pilots currently on flying status while the other three were nonflying personnel. Since the experiment involved colored stimuli, the color vision of each subject was tested with the American Optical Company Pseudo-Isochromatic Plates. All subjects gave perfect scores, so all had normal color vision.

PROCEDURE

Calibration of Lighting Apparatus:

With each viewing panel, red and white light were compared at three brightness levels. It was desired that these brightness levels conform as nearly as possible to the brightness levels used by pilots. In a previous experiment, Cole, McIntosh, and Grether (1) found the brightness levels of red flood light selected by twelve pilots during night flights. The pilots were asked to adjust their lighting for three conditions, as follows: "(1) minimum brightness required for safe flight, (2) brightness the pilot would use for normal operation, (3)

maximum brightness to meet a situation such as flying instruments at night wherein outside vision is of no concern." The average settings for red flood light under these conditions proved to be .003, .020, and .084 foot-Lamberts respectively. These results were in terms of the average brightness of the instrument markings. In the present experiment, the subject viewed the instrument panel by looking back and forth over the panel as he would in normal flight. In viewing the white panel, however, the subject fixated a point which was 7° of visual angle to the right of the center of the panel. This permitted the center of the white panel to stimulate the same part of the right eye which was used in measuring thresholds. Thus it was desirable to set the three brightness levels of red light as average brightnesses of the markings on the instrument panel, but as brightnesses at the center of the white panel.

Brightness measures of dial markings are difficult to make because of the small areas involved, so a special calibration panel was employed. This panel was first painted with flat black paint. A large circular patch of fluorescent paint was then placed in the center of the panel. Brightness measurements were made on the large area of fluorescent paint, which was placed in a position corresponding to the center of the instrument panel.

The next problem was to find the relation between the average brightness of the instrument panel and the brightness at the center of the panel. Since the pattern of brightness was entirely dependent upon the distribution of light falling upon the panel, this problem was solved by making brightness measures on a white panel which was placed in front of the instrument panel. A rectangle was marked off on the white panel which corresponded to the area of the instrument panel actually containing instruments. The white lighting was then set at an arbitrary intensity, and ten brightness measures were made at each of fifteen representative points on the rectangle. The actual points of measurement and the average brightness values obtained are shown in Table I. It will be noted that the illumination on the panel proved to be rather uniform. The average brightness of the entire fifteen points proved to be .078 Ft-L, whereas the brightness of the center of the panel proved to be .083 Ft-L. Hence the ratio of the average brightness at the center of the panel was 78:83. This ratio was used to find the desired brightness values of red light at the center of the instrument panel. These values are shown in Table II.

In order to facilitate testing, it was necessary to know the voltage under each lighting condition which would give the desired brightness. Thus under each of the six test conditions with red light, the voltage was determined which yielded the desired brightness. These measurements, as all other measurements involving brightness, were made with a Luckiesh-Taylor Brightness Meter. Ten measurements were made by each of three observers under each test condition, so each voltage was the average of thirty measurements. These voltage values are shown in Table IV and Table V.

The red and white lighting could have been matched in brightness, but red and white light of equal brightness may not yield equal legibility of aircraft instruments. The best assumption is that pilots will adjust the brightness of white light to give the same legibility of aircraft instruments as red light. For this reason the two lighting systems were equated on the basis of visual acuity.

In order to accomplish the above objective, a small Landolt ring was drawn with fluorescent paint on a flat black background. This ring was mounted in the center of a black panel, which was placed in the position to be occupied by the instrument panel. The red lighting was turned to one of the predetermined voltages for the instrument panel, for example, 8.9 volts. An observer then moved toward or away from the Landolt ring until he found a distance at which the outlines of the ring were just clearly discernible. When ten determinations of this distance had been made, the observer was placed at the average distance. Then the white lighting was used and the observer was allowed to vary the voltage until the outlines of the ring were again just clearly discernible. Ten determinations

TABLE I

PATTERN OF BRIGHTNESS IN FOOT-LAMBERTS OF INSTRUMENT COVERED AREA OF INSTRUMENT PANEL

	Extreme L	Middle L	Center	Middle R	Extreme R
Top	.071	.085	.092	.076	.067
Center	.069	.078	.083	.077	.066
Bottom	.073	.084	.093	.083	.069

TABLE II

BRIGHTNESS VALUES IN FOOT-LAMBERTS AT CENTER OF INSTRUMENT PANEL FOR RED LIGHT AND FOR EQUIVALENT* LOW COLOR TEMPERATURE WHITE LIGHT

	Average Brightness of Panel with Red Light (Ft-L)			
	.0030	.020	.084	
Red Light	.0032	.021	.089	
Equivalent* Low Color Temp. White Light	.0160	.051	.290	
Brightness Ratio: White/Red	5.0	2.4	3.3	Average: 3.57

*Criterion of equivalence: equal visual acuity.

TABLE III

BRIGHTNESS VALUES IN FOOT-LAMBERTS AT CENTER OF WHITE PANEL FOR RED LIGHT AND FOR EQUIVALENT* LOW COLOR TEMPERATURE WHITE LIGHT

	Brightness of Center of Panel with Red Light (Ft-L)			
	.0030	.020	.084	
Red Light	.0030	.020	.084	
Equivalent* Low Color Temp. White Light	.0150	.048	.274	
Brightness Ratio: White/Red	5.0	2.4	3.3	Average: 3.57

*Criterion of equivalence: equal visual acuity.

TABLE IV

VOLTAGE VALUES WITH INSTRUMENT PANEL WHICH PRODUCE THE BRIGHTNESS VALUES IN TABLE II

	Average Brightness of Panel with Red Light (Ft-L)			
	.0030	.020	.084	
Red Light	8.9	11.6	15.3	
Equivalent* Low Color Temp. White Light	6.5	7.9	10.8	
Voltage Ratio: Red/White	1.37	1.47	1.42	Average: 1.42

*Criterion of equivalence: equal visual acuity

of this voltage were made. Thus the voltage was found for white light which yielded the same visual acuity as the predetermined voltage for red light. This procedure was accomplished for all three of the predetermined voltages for red light on the instrument panel, using three different observers. Thus each voltage value for white light with the instrument panel was the average of thirty determinations, and these voltage values are shown in Table IV.

Once the voltage values for the white light with the instrument panel were determined, the brightness values at the center of the instrument panel could be determined. This was done by using the calibration panel with the patch of fluorescent paint, and by making ten brightness measurements at each voltage value. The averages were computed, and these brightness values of white light at the center of the instrument panel are shown in Table II. The brightness ratio of white light to red light which gave equal legibility of instruments was computed for each brightness level, and these values are also shown in Table II. The average ratio for the three brightness levels proved to be 3.57.

For each brightness value of white light at the center of the instrument panel, the average brightness of the instrument panel was computed. These three average brightnesses were then used as the brightness levels of white light in the center of the white panel, and these brightness values are shown in Table III. Once the brightness values were computed, the voltages required to produce the brightnesses were determined. This was done by making ten measurements of the voltage required to produce each brightness and computing the average values. These voltage values are shown in Table V.

TABLE V

VOLTAGE VALUES WITH WHITE PANEL WHICH PRODUCE THE BRIGHTNESS VALUES IN TABLE III

	Brightness of Center of Panel with Red Light (Ft-L)			
	.0030	.020	.084	
Red Light	9.0	11.2	14.6	
Equivalent* Low Color Temp. White Light	6.3	7.4	10.1	
Voltage Ratio: Red/White	1.43	1.51	1.45	Average: 1.46

*Criterion of equivalence: equal visual acuity.

The above calibration procedure allowed three comparisons of red and white light to be made with the instrument panel. The three intensities of red light were the intensities which have been found to be used by pilots under three different conditions of night flying. In each comparison, the red and white light were equated in visual acuity value and hence they produced equal legibility of aircraft instruments. The same three comparisons of red and white light were possible with the white panel. The brightness values at the center of the white panel were equal to the average brightness values of the dial markings on the instrument panel. Thus the white panel differed from the instrument panel in that it presented a solid stimulus area instead of discrete dial markings on a black background, and the white panel was whiter in color than the yellowish dial markings.

Testing Procedure:

Each subject was tested on four consecutive days. The first day was practice, so that the subject could become acquainted with the experimental situation and develop a stable criterion for threshold measurements, thus assuring reliable measurements. The last three days were for actual testing.

The same procedure was followed with all subjects on the practice day. The subject wore red goggles for twenty minutes prior to entering the dark room. After entering the dark room, the chin rest on the lighting apparatus was adjusted so that the subject's eyes were opposite the center of the viewing panel. The subject's stool was also adjusted so that he was comfortable with his chin in the chinrest. Ten more minutes were then allowed to complete the process of dark adaptation. A series of threshold measurements was made at the beginning of testing, in order to be sure the subject was completely dark adapted. All thresholds were measured by the method of limits, using an increasing brightness of test flash, and the subject was considered completely dark adapted when five consecutive thresholds were obtained which were essentially identical. The subject then turned to the lighting apparatus and was read the following instructions:

> When the lights come on, you will see a black cross on a white card. Look at the black cross immediately and continue to look at the cross as long as the lights are on. When the lights go off, turn immediately to the adaptometer and prepare for threshold measurements. Let me know as soon as you are ready to make threshold judgments.

The first lighting condition was turned on for a period of one minute. At the end of one minute, the lights were turned off and a stopwatch was started. The subject turned immediately to the adaptometer and a threshold was taken as quickly as possible. As soon as the subject reported seeing a test flash, the stopwatch was stopped. Thus both his threshold and the time required to obtain the threshold were measured. Threshold measurements were then continued until the subject was again completely dark adapted. The criterion of when the subject was re-adapted was when one threshold was obtained which was at least as low as the average dark adapted threshold obtained at the beginning of testing. As soon as the subject was re-adapted, another measurement was made with the same lighting condition. Then the lighting condition was changed and two more measurements were made. Whenever it was necessary to change lighting conditions, this was done in darkness. Altogether, two practice measurements were made under each of the six lighting conditions with red light. When the white panel was replaced by the instrument panel, the subject was read a new set of instructions, as follows:

> When the lights come on, you will see a panel of aircraft instruments. Look back and forth over this instrument panel as if check reading your instruments to see if any instrument reading deviates significantly from the desired reading. When the lights go off, turn immediately to the adaptometer and let me know as soon as you are ready to make threshold judgments.

TABLE VI

INCREASES IN ABSOLUTE THRESHOLD IN LOG MICRO-MICROLAMBERTS*

Subject	Average Resting Threshold Over All Three Test Days in Log Micro-Micro-lamberts	White Panel						Instrument Panel					
		Red Light .003 Ft-L	Low Color Temp White Light .015 Ft-L	Red Light .020 Ft-L	Low Color Temp White Light .048 Ft-L	Red Light .084 Ft-L	Low Color Temp White Light .274 Ft-L	Red Light .003 Ft-L	Low Color Temp White Light .015 Ft-L	Red Light .020 Ft-L	Low Color Temp White Light .048 Ft-L	Red Light .084 Ft-L	Low Color Temp White Light .274 Ft-L
1.	4.194	.070	.474	.350	.384	.446	.606	.256	.307	.262	.262	.211	.476
2.	4.233	.314	.368	.265	.471	.489	.561	.141	.141	.036	.054	.141	.522
3.	4.226	.248	.510	.333	.528	.664	.790	.124	.296	.162	.368	.108	.422
4.	4.144	.155	.384	.437	.455	.666	.581	.231	.265	.144	.404	.173	.505
5.	4.873	.316	.787	.316	.666	.437	.895	.177	.350	.162	.332	.162	.546
6.	4.116	.034	.299	.333	.508	.472	.562	.085	.209	.000	.263	.194	.544
Averages	4.298	.190	.470	.339	.502	.529	.666	.169	.261	.128	.281	.165	.502
Average No. of Seconds Required for Threshold Measurement		7.72	10.05	8.11	9.77	8.72	9.11	8.39	7.83	8.05	9.22	8.72	9.72

*Each value is the average of three measurements.

The procedure on the actual test days was essentially the same as on the practice day. On each test day, the completely dark adapted level was established at the beginning of testing when five thresholds were obtained which were essentially identical. Three thresholds were then obtained after each of four different lighting conditions, and the subject was completely re-adapted prior to each measurement.

The three thresholds obtained with a given subject after a given lighting condition, were averaged. The increase in this average threshold over the average dark adapted threshold at the beginning of testing on the same day was then computed. This increase in threshold was the score for that given subject and that given lighting condition. Thus each subject yielded a score for each of the twelve lighting conditions. The lighting conditions were presented to the different subjects in a counterbalanced order to control practice effects.

RESULTS

The basic results of the experiment are shown in Table VI, which indicates the average increase in threshold for each subject under each lighting condition. The different subjects yielded highly similar patterns of results, but some subjects showed greater increases in threshold than others. The average time required to measure thresholds is also shown for each lighting condition. Since the average time required to measure thresholds was quite similar for all twelve lighting conditions, this factor was well controlled. The average time required to measure thresholds under all twelve lighting conditions was only 8.78 seconds. Since little dark adaptation could occur during this period, the obtained thresholds must approximate very closely the visual state immediately after viewing the preadaptation stimuli. Hence the increases in threshold in Table VI may be regarded as quite accurate.

The average increases in threshold for all six subjects under all twelve lighting conditions are shown in Table VII. All lighting conditions produced increases in threshold which were small but significantly greater than zero. The statistical significance of each increase was determined by means of a t-test, and the significance of each increase is indicated in Table VII. The differences between the effects of red light and low color temperature white light upon thresholds are also shown. In all six comparisons of the two kinds of lighting, the low color temperature white light produced a slightly greater increase in thresholds than the pure red light. The differences were significantly greater than zero in five out of six cases, as determined by t-tests and indicated in Table VII.

An analysis of variance was performed to test the statistical significance of the major variables in this experiment, and the results of this analysis of variance are shown in Table VIII. It may be noted from Table VII that the loss of dark adaptation was slightly greater when low color temperature white light was used instead of red light, when higher brightness levels were used, and when the solid white panel was used instead of the instrument panel. The effects of all three of these variables proved significant at either the .01 or .001 level. Individual differences also proved significant at the .001 level, and certain of the interactions proved significant. It may be noted that the interaction between brightness level and color of lighting was different with the instrument panel and with the white panel. With the instrument panel the difference between the two lighting systems increased as brightness increased, while with the white panel the reverse occurred. As a result of this difference between the two panels, the overall interaction between brightness and color proved insignificant. The panel of greatest practical interest, however, is the instrument panel. When the interaction between brightness and color was tested by an analysis of variance on the instrument panel alone, the interaction proved significant at the .001 level. Thus when the instrument panel was used, the difference between the effects of low color temperature white light and red light upon dark adaptation increased significantly as the

TABLE VII

AVERAGE INCREASES IN ABSOLUTE THRESHOLD IN LOG MICRO-MICROLAMBERTS

	White Panel Brightness in Foot-Lamberts of Red Light at Center of Panel			Instrument Panel Average Brightness in Foot-Lamberts of Panel with Red Light		
	.003	.020	.084	.003	.020	.084
Red Light	.190*	.339†	.529†	.169**	.128*	.165†
Low Color Temp. White Light	.470**	.502†	.666†	.261†	.281**	.502†
Difference between Red and White Light	.280**	.163*	.137	.092*	.153*	.337†Av: 194

*Values significant at the .05 level.
**Values significant at the .01 level.
† Values significant at the .001 level.

TABLE VIII

RESULTS OF ANALYSIS OF VARIANCE

Source	Sum of Squares	Degrees of Freedom	Variance Estimate	F-Ratio	P-Value
Color of Lighting	.677	1	.677	35.6	.01
Brightness Levels	.499	2	.250	41.7	.001
Panels	.708	1	.708	41.6	.01
Subjects	.170	5	.034	11.3	.001
C x B Interaction	.019	2	.010	2.5	Insignificant
C x P Interaction	.000	1	.000	0.0	Insignificant
C x S Interaction	.094	5	.019	6.3	.01
B x P Interaction	.069	2	.034	3.8	Insignificant
B x S Interaction	.064	10	.006	2.0	Insignificant
P x S Interaction	.084	5	.017	5.7	.01
C x B x P Interaction	.114	2	.057	19.0	.001
C x B x S Interaction	.042	10	.004	1.3	Insignificant
C x P x S Interaction	.054	5	.011	3.7	.05
B x P x S Interaction	.091	10	.009	3.0	.05
C x B x P x S Interaction	.034	10	.003		
Total	2.719	71			

brightness level increased. This means that the lower the brightness level used, the less will be the loss in dark adaptation resulting from the use of low color temperature white light instead of red light.

DISCUSSION

It was discovered during calibration of the apparatus that the brightness of low color temperature white light on the dial markings had to be greater than that for red light in order to attain equal visual acuity and equal legibility of instruments with the two lighting systems. This means red light has two advantages over low color temperature white light for the preservation of dark adaptation. The well known advantage is that when red and white light are equated in brightness above the scotopic level, the red light has a smaller effect upon the sensitivity of the scotopic system. This study indicates that red light can also be used at a lower brightness than white light. Since the two kinds of lighting were equated for legibility in this study, red light was given both of its advantages and an accurate comparison of the effects of the two kinds of lighting upon dark adaptation was obtained.

It was noted during the experiment that if the brightnesses of red and white lighting on the dial markings were equated, the black background looked much darker with the red light. Thus the visual contrast between dial marking and background was greater with the red light than with the white light. One reason for this was the greater reflectance of the fluorescent paint for red light than for white light, as may be seen in Figure 3. Since the per cent reflectance curve for the black background paint was flat, there was a somewhat stronger physical contrast between dial marking and background in the case of the red light. This factor could not be very important in this case, however, since the white light was low in color temperature and composed largely of the red wave lengths. It is believed that the greater visual contrast with the red light was due primarily to the Purkinje shift. The dial marking brightnesses in this study were all slightly above the cone threshold. Thus the Purkinje shift may be expected to occur to some extent between the brightness of the dial marking and the brightness of the background. When a shift occurs from photopic to scotopic brightness levels, the greater sensitivity of the eye to white light than to red light becomes more marked. Hence the subjective background brightness would be expected to be greater with white light than with red light, and the visual contrast between dial marking and background would be greater with red light. This explanation seems to be supported by the findings of Martin and Pearse (4). At brightness levels from 1 f. c. upwards they found no appreciable difference between speed of reading in red and white light of equal brightness. From 0. 05 f. c. to 0. 2 f. c., however, the red light had a definite advantage. They also found visual acuity to be essentially the same with red and white light at 6. 0 f. c. At 0. 6 f. c., however, acuity was greater with red light than with white light and at 0. 06 f. c. the difference was even more marked. Thus with both speed of reading and visual acuity, the advantage of red light over white light appears when brightness is reduced to the level at which the Purkinje shift occurs

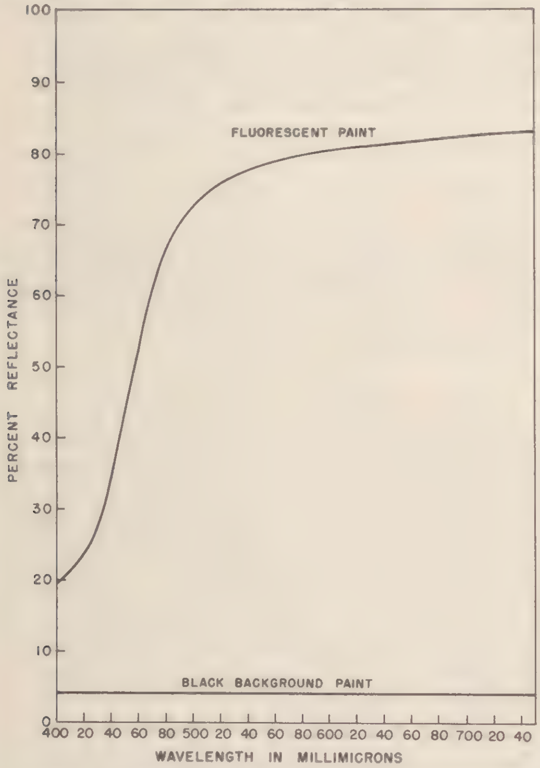

Figure 3. Percent reflectance curves for fluorescent paint and black background paint.

Although the instruments were equally legible with red and white light only when the white light produced a higher brightness of the dial markings, the red light required the higher voltage value. This was due to the fact that the red filters which were used to obtain the red light cut out so much of the other wave lengths. The average voltage ratio required for the red and white lights with the intrument panel was 1. 42, which is a fair estimate of the relative voltages required with the two lighting systems. It should be noted, however, that the

voltage values in Table IV are correct only for the lighting configuration in the present experiment. The values would be different if the number of lighting units or the distance between the lighting units and the instrument panel were changed. It should also be noted that the voltage ratio between the red and white lighting systems is correct only for the lighting configuration of the present experiment. This is true since there is not a linear relation between voltage and light intensity.

The losses of dark adaptation which resulted from illuminating the instrument panel with pure red light are particularly interesting. It has been assumed that red light at low intensity gives optimum preservation of dark adaptation, and this study indicated how well that end is achieved. With all three of the brightness levels employed, the losses of dark adaptation were statistically significant. The amount of loss, however, was below .17 log $\mu\mu$ L in all three cases. The small magnitude of the loss with pure red lighting suggests that little further improvement can be made in instrument lighting from the standpoint of preserving dark adaptation. In order to further improve vision for outside objects, it may be more important to eliminate canopy and windscreen reflections which mask the direct view of outside objects. When the instrument panel was illuminated with red light, the results showed no increased loss of dark adaptation at the higher brightness levels. It seems likely that there is some additional loss with increase in brightness which was obscured by chance factors. It may be assumed, however, that the additional loss is small in magnitude since it did not show up in the present study.

When the effects of low color temperature white light are compared with the effects of red light, the low color temperature white light produced a slightly greater loss of dark adaptation. When the instrument panel was used at the normal brightness level which pilots use in night flying, the low color temperature white light raised visual thresholds by only .153 $\mu\mu$ L more than the red light. This difference represents only a small part of the total range of dark adaptation, and the difference may have no practical significance. Reliance upon outside vision appears to be diminishing in most Air Force operations. Furthermore, canopy and windscreen reflections can seriously limit outside vision from aircraft at night. Even when low color temperature white light is used, the limiting factor in night vision from aircraft may be not dark adaptation, but reflections which mask the view of outside objects. Further research is needed to compare the relative effects of these two factors. It may be that the advantages of complete or nearly complete dark adaptation cannot be utilized.

When low color temperature white light is used with the instrument panel, the loss of dark adaptation increases as the brightness increases. Hence when low color temperature white light is used, it is advisable from the standpoint of dark adaptation to keep the brightness as low as possible. Since brightness is more critical with low color temperature white light than with red light, this may be considered an advantage of red light.

Thresholds after adaptation to the uniformly white panel averaged 198 log $\mu\mu$ L (for red and white light combined) above those for the simulated instrument panel. This indicates the approximate magnitude of the sacrifice in dark adaptation which would be expected if the instrument panel and dials were white with black markings, instead of the opposite relationship used at present. The suggestion is frequently heard that the space between the instruments should be gray rather than black, in order to make the instruments stand out better, and to reduce daytime contrast between the panel and outside brightnesses. The present findings do not indicate the exact sacrifice in dark adaptation which this change would entail, but certainly the sacrifice would be considerably less than the value of .198 log $\mu\mu$ L found for a uniform white panel. Before a gray panel is recommended, the effect of such a change on canopy and windscreen reflections should be evaluated.

Although dark adaptation has been stressed in the past in comparing aircraft lighting systems, at least two other factors are also important. One factor is the visibility of the

lighting to an enemy observer. If red and white lights are equated above the scotopic level, the white lighting is visible at a greater distance than the red to a dark adapted enemy observer. This is due to the Purkinje shift. Furthermore, low color temperature white light must be used at a higher brightness than red light. Thus red light has an advantage over low color temperature white light from the standpoint of visibility to a dark adapted enemy observer. The second factor is the degree to which colored surfaces within the aircraft maintain their natural color under cockpit lighting. Under red flood lighting all colors appear red, gray, or green, depending upon whether the colored surface is brighter than, equal to, or darker than the background against which it is presented. This is the phenomenon of simultaneous color contrast, which has been verified using standard federal colors under red flood lighting. Hence map reading, for example, is difficult under pure red lighting because the differently colored lines and elevation contours do not maintain their normal colors and contrast relationships. Under low color temperature white light, on the other hand, it has been demonstrated that standard federal colors maintain a more natural appearance and map reading is easier. In summary, it is clear that red light is superior for maintaining dark adaptation and avoiding detection by enemy observers, but white light is superior for color discrimination within the plane.

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4. Martin, L. C. and Pearse, R. W. B. Ease of Reading and Visual Acuity in Red and White Light. Admiralty Research Laboratory Report No. N3/0.360. August 1942, pp. 1-6.

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Discussion:

Mr. Sidle asked whether the study of only three brightness levels was adequate.

Dr. Brown commented that in the night fighting situation, the pilot is using radar and has no concern with the visibility of objects outside the aircraft. For this reason, the Air Force interest was primarily in improving instrument reading and they were concerned less with interference with visibility of objects outside the aircraft.

Mr. Fred Brown stated that he felt that the problem of reflection of light from the wind screen is a very serious one. It is very difficult to eliminate this kind of reflection. The presence of a reflected glare on the wind screen is probably more important in limiting visibility of objects outside the aircraft than is the dark adaptation of the pilot.

Dr. Blackwell commented on the usefulness of the present data in evaluating the loss of visibility for objects outside the aircraft caused by bright instrument lights. In the first place, the method of presenting data makes it difficult to evaluate the loss in detection probability. Comparing the loss in dark adaptation makes the effect seem smaller than it really is since the dark adaptation process covers such a wide range. The proper thing to do would be to compute the loss in visibility to be expected from the difference in adaptation produced by the instrument lights. It would be possible to employ the Tiffany Visibility Forecasting Nomographs to evaluate the extent of the loss in visibility produced by the loss in dark adaptation.

Dr. Brown stated that it is difficult to translate the present data into data on the range of visual detection. He asked that the present report be considered a preliminary report. He stated that evaluation of the loss in visibility range could be studied subsequently.

Dr. Blackwell expressed his concern that the form of data analysis in the report would lead to the unwarranted conclusion that visual ranges of objects outside the aircraft would be but little influenced by the change from red to low color temperature white light. For this reason, an evaluation of the losses in visual range might well be undertaken prior to publication of the results.

Dr. Tousey stated that a study had been made during the war to determine the extent to which a loss in adaptation increased the time required to detect an object at threshold. This criterion of loss of visibility due to loss of adaptation was found to be the most sensitive test of the adequacy of dark adaptation.

Col. Byrnes stated his concern with the statement that fighter pilots do not use the unaided eye in making night kills. He stated that fighter pilots can shoot better by eye than by radar.

Dr. Davis emphasized that at low altitudes, two or three thousand feet, visual detection must be employed and radar is not practicable.

RECENT ADVANCES IN THE CALCULATION OF VISIBILITY FROM AIRCRAFT

Seibert Q. Duntley

A method for calculating the minimum inherent contrast which will be visually detectable by an observer in an aircraft located at a given point in the sky was described to this Committee at its Fifteenth Meeting (February 12, 1946), and published accounts of the method appear in Volume 2 of the Summary Technical Report of N. D. R. C. Division 16 and in the Journal of the Optical Society of America.[1,2]

This method, based upon the Nomographic Visibility Charts prepared by the Tiffany Foundation, is incapable of solving directly for the limiting slant range at which any given object can be detected. In such cases, values of liminal inherent contrast for assumed values of slant range must be determined and the liminal slant range found by interpolation. This procedure is cumbersome, time consuming, and invites mistakes. A modification of the Nomographic Visibility Charts which enables liminal slant ranges to be found directly without successive approximations or interpolation has been devised by members of the Staff of the MIT Visibility Laboratory.* These new charts have been constructed under a contract with the Office of Naval Research for the production of a handbook showing the space volumes over the surface of the sea within which a fully submerged submarine can be visually detected. The extensive calculations involved in producing this handbook have been greatly minimized by the construction of the new type Nomograph.

The Nomographic Visibility Charts produced by the Tiffany Foundation represent Equation (1)

$$C_r = C_o \left[1 - S\left(1 - e^{(\ln 50)\,\overline{R}/v_o}\right)\right]^{-1} \tag{1}$$

Where:

C_r = apparent contrast of target

C_o = inherent contrast of target

S = sky-ground ratio

$\overline{R}$ = optical slant range

v_o = meteorological range at sea level

The derivation of this equation and the meaning of the symbols which it involves have been discussed many times before this Committee and are fully set forth in references given above. The Tiffany Nomograph for inclined paths of sight is shown in Figure 1. The reader is referred to the above references for illustrative examples of the use of this chart.

A review of the mathematical structure of the nomograph disclosed that the scales of SKY-GROUND RATIO and CONTRAST can be replaced, to an approximation better than one per cent, by a single scale of the ratio: INHERENT CONTRAST SKY-GROUND RATIO.

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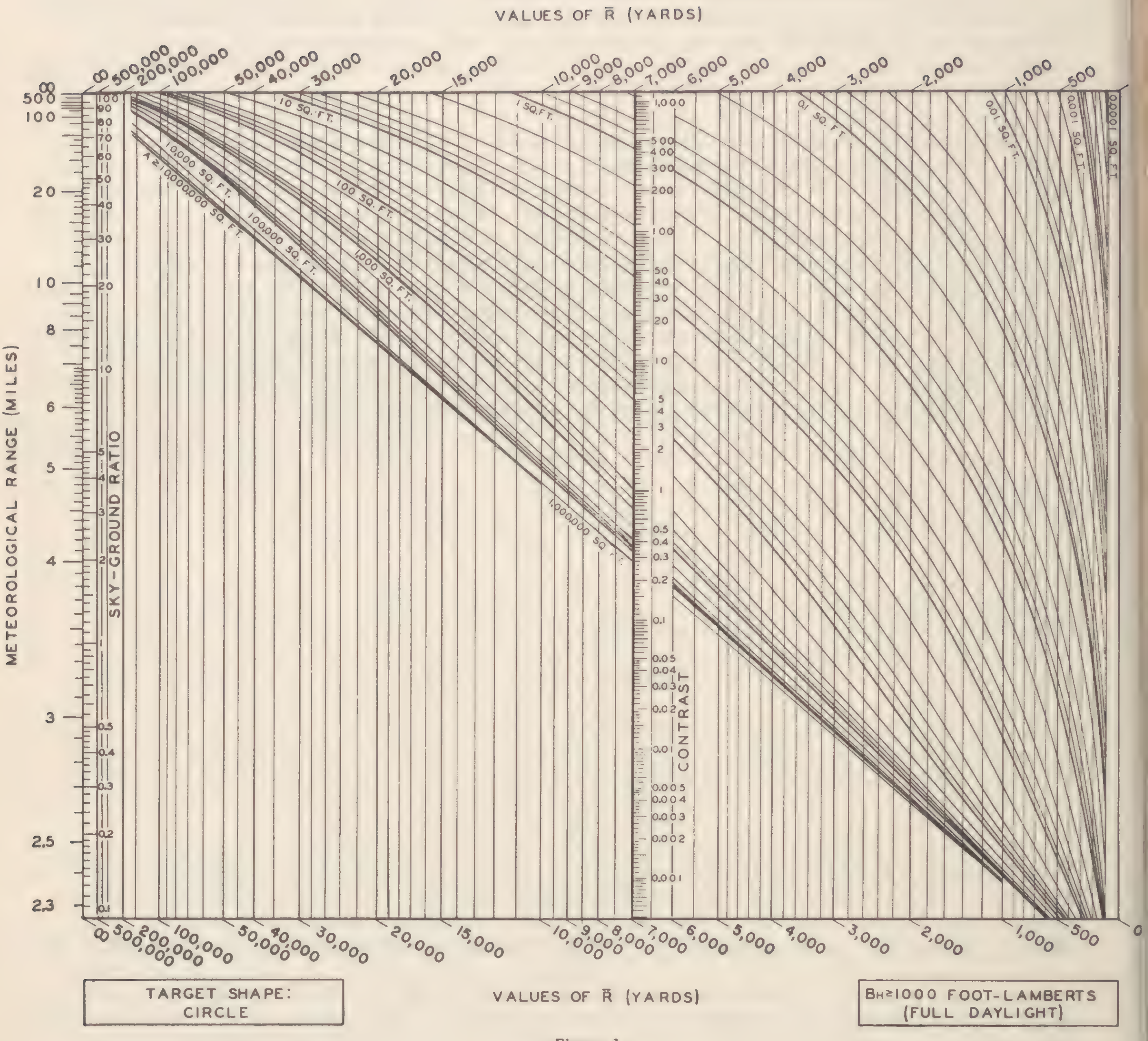
*Those responsible for the new charts are Mrs. Frances Culver, Mr. Roger Franklin, and Mr. William Whitney

[1]Duntley, S.Q. ''The Reduction of Apparent Contrast by the Atmosphere'' J. Opt. Soc. Am. 38,179 (1948).

[2]Duntley, S.Q. ''The Visibility of Distant Objects'' J. Opt. Soc. Am. 38,237 (1948).



VALUES OF R̄ (YARDS)
METEOROLOGICAL RANGE (MILES)
SKY-GROUND RATIO
CONTRAST
1 SQ. FT.
10 SQ. FT.
100 SQ. FT.
1,000 SQ. FT.
10,000 SQ. FT.
100,000 SQ. FT.
1,000,000 SQ. FT.
A ≥ 10,000,000 SQ. FT.
0.1 SQ. FT.
0.01 SQ. FT.
0.001 SQ. FT.
0.0001 SQ. FT.
TARGET SHAPE: CIRCLE
BH ≥ 1000 FOOT-LAMBERTS (FULL DAYLIGHT)

Figure 1.

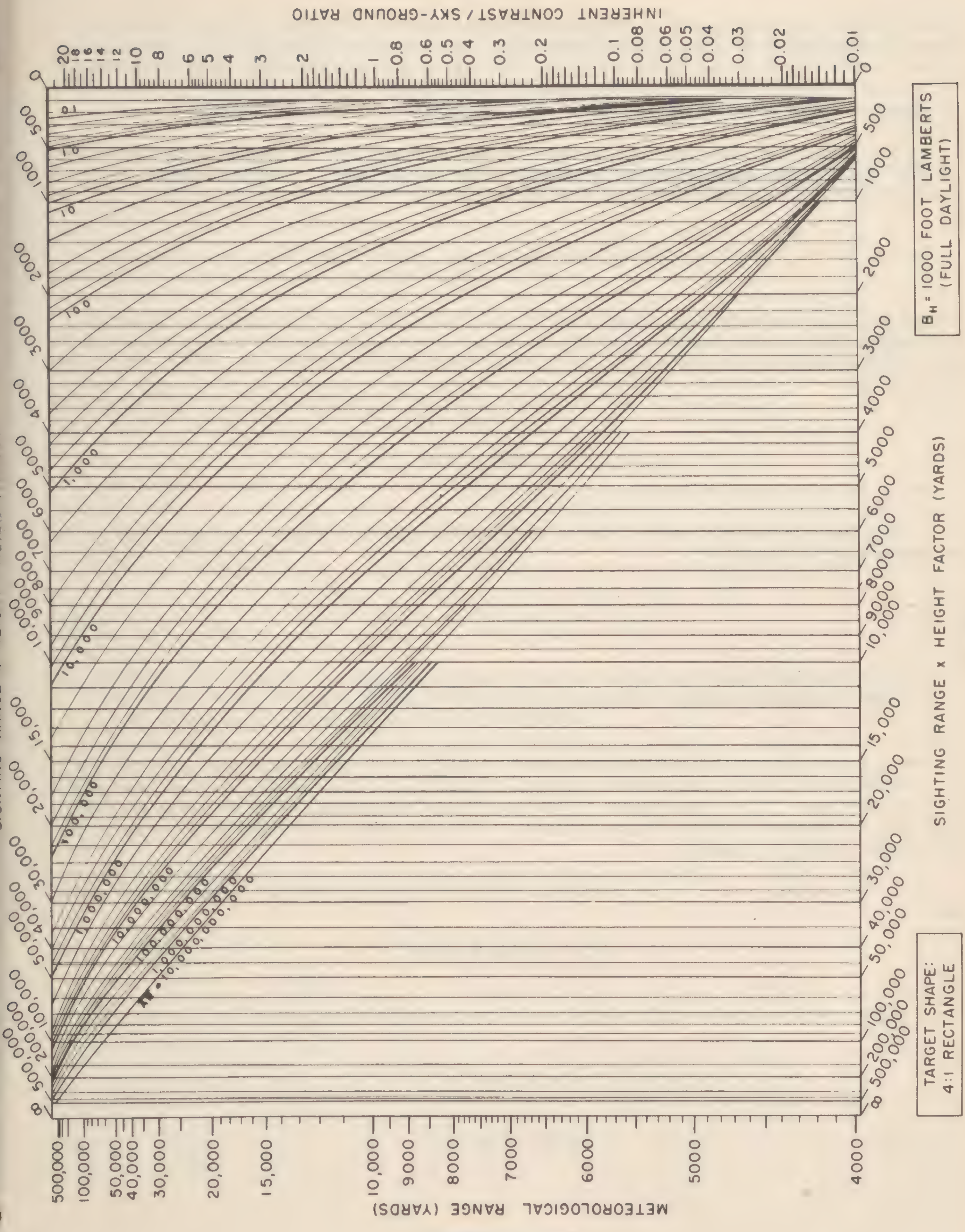

INHERENT CONTRAST / SKY-GROUND RATIO
SIGHTING RANGE x HEIGHT FACTOR (YARDS)
SIGHTING RANGE x HEIGHT FACTOR (YARDS)
METEOROLOGICAL RANGE (YARDS)
B_H = 1000 FOOT LAMBERTS
(FULL DAYLIGHT)
TARGET SHAPE:
4:1 RECTANGLE

Figure 2.

Such a scale is shown on the new type nomograph depicted in Figure 2. This scale has been so arranged that it incorporates the factor of two recommended on Page 249 of Reference 2. Thus, the values produced by the new nomograph are in terms of sighting range rather than liminal range. (Sighting range is that distance at which the average observer experiences a threshold of confidence and becomes aware of seeing the object.)

The upper and lower horizontal scales of the nomographic visibility charts are "values of $\overline{R}$". The optical slant range $\overline{R}$ is related to the slant range R and the inclination θ of the path of sight by Equation (32) of Reference 2:

$$\overline{R} = 21,700 \csc \theta \, (1 - e^{-R \sin \theta / 21,700})$$

where R and $\overline{R}$ are to be measured in feet. The constant 21,700 feet is based upon obsolete data; a value of 30,000 feet or 10,000 yards is preferable. If the ratio R/Y is substituted for $\csc \theta$ in the above equation, a more useful form results:

$$\overline{R} = R \left[10^4 \, Y^{-1} \, (1 - e^{-10^{-4} Y}) \right] \qquad (2)$$

where Y is the altitude of the aircraft in yards.

Equation (2) does not involve the inclination of the path of sight. Let <u>height factor</u> H be defined by the equation:

$$H = 10^4 Y^{-1} \, (1 - e^{-10^{-4} Y}) \qquad (3)$$

The upper and lower horizontal scales of the nomographic visibility charts can usefully be labeled "SIGHTING RANGE X HEIGHT FACTOR", since $\overline{R} = RH$.

The curved lines in Figure 1 represent Tiffany contrast thresholds for the human eye as they apply to objects of effective projected area $\overline{A}$. Each curve is a locus of constant $\overline{A}$. At each point where one of these curves crosses one of the vertical $\overline{R}$ lines, the $\overline{A}\,\overline{R}$ product is known. Thus every point on the nomogram represents a definite value of $\overline{A}\,\overline{R}$, and lines of constant $\overline{A}\,\overline{R}$ can be constructed. This has been done to produce the modified nomograph shown in Figure 2.

In the special case of a flat horizontal object of area A, the effective area $\overline{A}$ is given by:

$$\overline{A} = A \sin \theta \, (\overline{R}/R)^2 \qquad (4)$$

If the relations $\sin \theta = Y/R$ and $\overline{R} = RH$ are substituted in equation (4), it becomes:

$$\overline{A} = A \, Y \, H^3 / \overline{R}$$

Thus:

$$\overline{A}\,\overline{R} = A \, Y \, H^3 \qquad (5)$$

The curved lines on Figure 2 may then be considered as representing constant values of the product A Y H^3. In the case of a non-horizontal object, the area A of its horizontal projection must be found.

The use of the new type chart will be illustrated by the following numerical example:

Let it be required to find the sighting range for a horizontal target of unit inherent contrast having an area A = 830 square feet for an observer flying at an altitude of 4500 feet (1500 yards) on a day when the meteorological range at sea level v_o = 20,000 yards. Let the sky-ground ratio S = 1/2.

Substitution in equation (3) yields H = 0.929. The product A Y $H^3 = 10^6$ ft^2 yards. INHERENT CONTRAST/SKY-GROUND RATIO = 1/2 = 2.

Place a straight edge across Figure 2 in such a manner that it connects 20,000 yards on the scale of meteorological range with 2 on the scale of inherent contrast/sky-ground ratio. From the point where the curve for 1,000,000 ft^2 yards is intersected by the straight edge move straight up or straight down to a reading of 11,000 on the scale of SIGHTING RANGE X HEIGHT FACTOR. The sighting range R is then:

$$R = 11{,}000/0.929 \doteq 11{,}800 \text{ yards.}$$

At this slant range the object will be seen with threshold confidence.

Discussion:

Mr. Middleton expressed his enthusiasm for the work reported by Dr. Duntley. Mr. Middleton stated that the assumption that the atmosphere attenuates light exponentially will not however be good enough for all purposes.

ON THE PSYCHOPHYSICAL BASIS OF METEROLOGICAL ESTIMATES OF "VISIBILITY"*

by W. E. Knowles Middleton and A. G. Mungall

Abstract

Before the results of telephotometry or of measurements of atmospheric scattering can be used to calculate the visual range in daylight, we must know the least contrast between a "visibility mark" and its surroundings which will lead the observer to report the mark as visible. A knowledge of the dispersion of this quantity is also of importance if the reliability of estimates of "visibility" has to be calculated. This paper reports direct measurements of the contrast, made by pointing a photoelectric telephotometer alternately at a mark and at the sky just adjacent to it, the mark having been chosen by a trained meteorological observer as being just at the visual range. The results of 1000 observations show a range of values of about 20:1. It is concluded that the present instructions for the estimation of "visibility" are chiefly to blame for this state of affairs, and that a criterion of <u>detection</u> should be substituted for the present one of <u>recognition</u>.

1. Statement of the Problem

At all important meteorological stations estimates of "the visibility" are part of each observation of the weather. In order to facilitate these estimates during the hours of daylight, a number of marks are chosen, preferably appearing against the horizon sky and dark in color, at various distances but subtending, as far as possible, similar angles of the order of one degree in each dimension. There will necessarily be a good deal of variation in the sizes and shapes of the natural objects visible from any station, and the use of very extensive ($> 10^{\circ}$) and very small ($< 0.1^{\circ}$) objects is discouraged. These several requirements are set out officially in Resolution 147 of the Conference of Directors, Washington, 1947 (O. M. I. 1948, p. 145). To this resolution is appended two notes, which are quoted in full because of their importance in this problem.

> "Note 1. There has been a difference in the instructions in different countries in regard to daylight visibility. In some countries daylight visibility has been determined by the distance at which the outline of objects seen against the sky disappears. In other countries the instruction has been that visibility is the distance at which an object such, for example, as a tree can be recognized as a tree.
>
> "Note 2. Thus the instructions of Meteorological Services should be 'the distinguishing of objects as such'."

While these statements are far from clear, there is no doubt that they are intended to impose on the observer a criterion of recognition, not merely of detection. These instructions merely made official what was already the practice in most countries.

It has been recognized for a long time that such estimates of "visibility" leave much to be desired, and as early as 1921 attempts at instrumental measurement began** to be

*Contribution from the Division of Physics, National Research Council of Canada, Ottawa.

**For an account of the earlier instrumentation see Middleton 1941, chapter 7.

made. The first of these were empirical, but after the theoretical investigations of Koschmieder (1924) attention centered on the measurement of the extinction coefficient σ of the atmosphere It may be shown that the visual range of a black object rising against the horizon sky is given by the formula

$$V = \frac{1}{\sigma} \log_e \left| \frac{1}{\epsilon} \right| \tag{1}$$

In this equation ϵ represents the least contrast that the eye can appreciate under the prevailing conditions of (1) background luminance (2) angular size of object. The contrast of such an object-background field is defined as

$$C = \frac{B - B'}{B} \tag{2}$$

where B is the luminance of the object, B' that of the surroundings, namely, the horizon sky. Equation (1) is not seriously in error for any dark objects.

Very extensive investigations of the dependence of ϵ on the two variables mentioned above were made during the second world war at the Tiffany Foundation and reported on by Blackwell (1946). When simultaneous measurements of σ, and estimates of V, were used to calculate ϵ by means of equation (1), however, (Houghton 1939, Douglas & Young 1945) it was found that the values obtained ranged from five to ten times the values given by the Tiffany experiments. It was not immediately obvious why this should be so, and a great deal of rather speculative discussion took place. The difficulties of this sort of indirect measurement finally led one of us to attempt to make direct measurements of the contrast between the mark and its surroundings at the moment when a meteorological observer identifies it as being at the visual range. This was done with a specially constructed photoelectric telephotometer.

2. Apparatus

The telephotometer need not be described in much detail. It consists of a very well-baffled telescope having an objective 4.5 cm. in diameter and 75 cm. in focal length, with an aperture in the focal plane giving a field of view 2 minutes of arc in angular diameter. A field lens immediately behind this aperture forms an image of the objective on the cathode of a photomultiplier tube, type 1P22. Filters were provided to correct the spectral sensitivity of the 1P22 to an adequate approximation to the luminosity curve of the normal eye (Fig. 1).

Immediately in front of the objective is a prism of small angle, which produces a deviation of 4.5 minutes of arc. This can be rotated in one plane through an angle of 180°, so that if the telescope is directed towards the edge of a visibility mark, fields just inside and just outside the mark can be presented alternately to the photomultiplier tube (Fig. 2). A finder telescope (a standard telescopic rifle sight) is mounted on the main telescope for aiming it accurately.

In order to obtain the maximum speed of reading, the photomultiplier tube is connected through a cathode-follower circuit to a high-speed recording potentiometer. The prism being moved through 180° in each direction at intervals of about two seconds, twenty or thirty readings are recorded in such a way that the mean difference B - B' may easily be obtained by estimation. If the deflection is kept at about 25 cm. by adjustment of the voltage on the photomultiplier tube dynodes, the contrast can be measured to one or two parts in a thousand, depending on the steadiness of the atmospheric conditions.

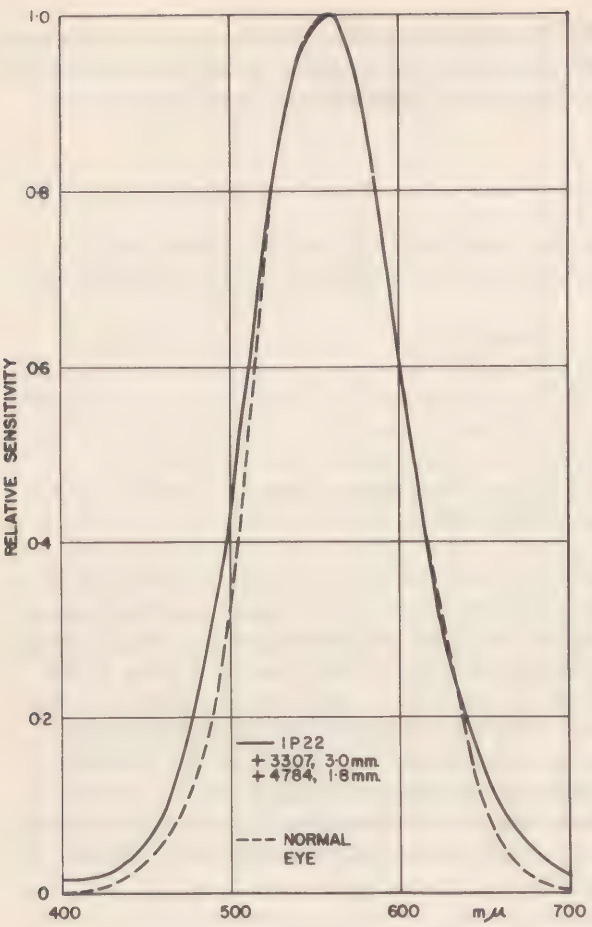


Figure 1. Spectral sensitivity of photocell-plus-filter combination used, compared with the luminosity curve of the normal eye.

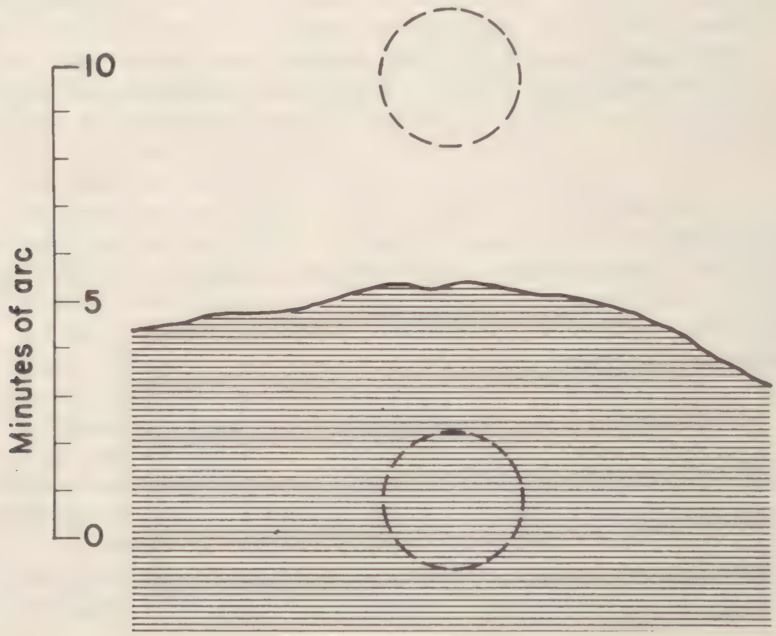


Figure 2. Fields selected by rotating the prism.

The linearity of the instrument was carefully checked and found more than adequate. In addition, a very severe test for stray light was applied. The instrument was directed at the centre of a white disk subtending 10 min. of arc. supported on a thin rod so as to appear against the sky. A large black screen was then placed behind the disk (see Fig. 3) and the luminance of the disk measured. The screen was then removed, and the apparent increase in luminance due to scattered light found to be only 1.1 per cent. It was therefore concluded that since under the conditions of observation there are no large contrasts near the direction of view, the effect of stray light in the instrument might be neglected.

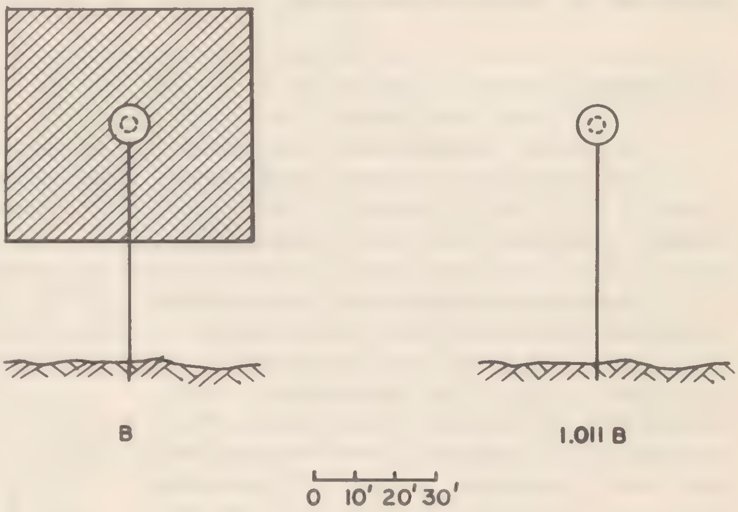


Figure 3. Test for stray light (see text).

3. The Program of Observations

A short series of observations was made in the summer of 1950, mainly by physicists (Middleton and Chapman 1950). It was then decided to install the apparatus at an airport meteorological station, and use the observations made by the regular meteorological observers. Through the kindness of Mr. Andrew Thomson, Controller of Meteorological Services, and of the Commanding Officer of Rockcliffe Air Station, the instruments were installed outside the meteorological office at that station, which is near Ottawa.

While these arrangements were being made, the available visibility marks were surveyed and a plan prepared. Forty-two objects were finally chosen, at distances ranging from 340 metres to 26.3 Km. Twelve of these were trees or groups of trees; seven were buildings or other structures; the rest were the crests of hills, all the marks at distances of more than 8 Km. being of this kind. The distances of the more distant marks were obtained by triangulation, the nearer ones with a rangefinder.

The program of observations was conducted by one of us (A. G. M.) during the hours 0830 to 1630 on most days when the visual range was less than about 25 Km., except that observations had to be ended earlier during December and January. In clearer air, no useful measurements were possible. The observations covered the period 21 November, 1950 to 6 September, 1951, and were discontinued when 1000 observations, considered to be reliable, had been accumulated. Twelve observers took part, but the estimates of one were felt to be so erratic that they were not used.

The observers were aircraftsmen and non-commissioned officers of the Royal Canadian Air Force, and had had varying amounts of experience as meteorological observers before the start of the experiment, ranging up to eleven years. Six had had more than three years' experience. Only one observer was nearly without experience, and it is felt that the group was representative of what might be found at any military station.

Care was taken to disturb the routine of observation as little as possible. When the experimenter saw that an estimate of the visual range was being made, he would ask the observer, "Which mark did you consider to be at the visual range just now?" He would then immediately train the telephotometer on the mark and make the measurement of contrast. The electronic circuits were kept in operation, so that only a few seconds elapsed between the observer's estimate and the instrumental reading.

The natural curiosity of the observers about the experiment was satisfied by explaining that it was designed to investigate the possibility of improving the techniques of observation. It is highly probable that the effect of the experiment was to make the observers somewhat more careful than they would otherwise have been, so that the disturbing results presented in the next paragraph may well be more favorable than they ought to be.

4. Results

Since the contrast was measured to three significant figures, the 1000 observations were analyzed into classes 0 - 0.0095, 0.0095 to 0.0195, etc., with the result shown in Table I. As will be seen by the frequency diagram, Figure 4, the distribution is strongly skewed, the mean of 0.042 contrasting with a mode of 0.024 and a median of 0.030.

The range of values of contrast included in Figure 4 covers a range of values of V of more than three to one for any given state of the atmosphere, calculated by equation (1). It is surely not necessary to make any great display of statistical treatment of such an alarming result. It is our duty, however, to anticipate the possible question whether such a result could have arisen from one or two bad observers. The answer is that the 74 observations of contrast greater than 0.0895 were distributed among all the observers but one. From a practical standpoint it would also seem to be of importance that one observation in fourteen is in this category.

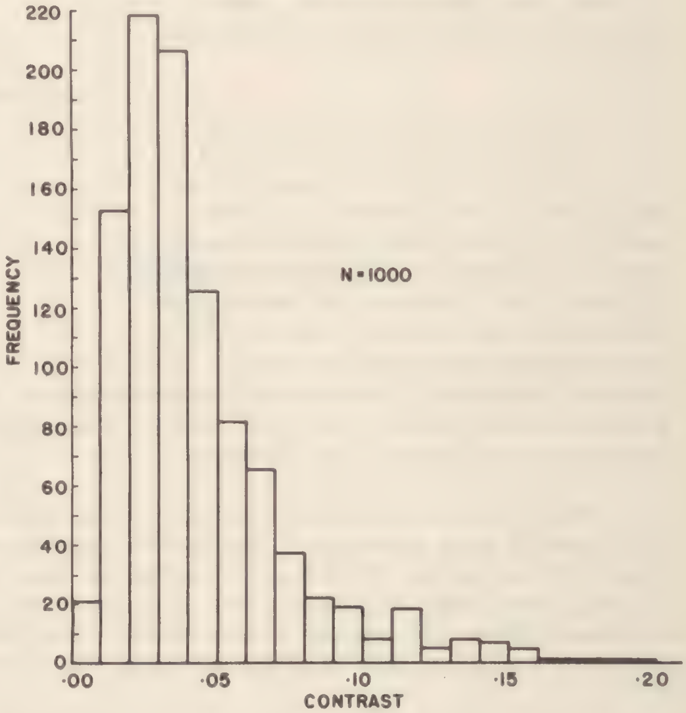


Figure 4. Frequency distribution of measured values of contrast, Rockcliffe, Ontario, Nov. 1950 to Sept. 1951.

The second objection might be that some anomalous marks were being used. It is a partial answer to say that the marks were chosen in the manner usual at meteorological stations. None of the marks actually used were less than about $1/2^{\circ}$ in one dimension, and if some of them were smaller than might be desired it was for the usual reason that no better mark was available. An examination of Table II, however, shows no obvious relation between the size of the mark and the number of observations of high contrast, as may be emphasized by comparing the pairs 25 and 27, 26 and 37. Mark 37 ought to have been a good one, but had an exceptionally high median contrast as well as a bad record of aberrant observations. Marks 4 and 9 form another instructive pair. Even the marks with neither dimension less than 0.4° offer quite enough observations of high contrast to cause concern about the whole procedure.

5. Comparison with Earlier Measurements

The present frequency distribution looks remarkably like that which may be deduced from the observations taken on Mount Washington in 1943 and 1944 (Van Lear, 1945). This is shown in Figure 5. It was obtained in an entirely different manner, namely from the result of combining (by Eq. 1) telephotometer observations of σ with direct estimates of V.

Although the present technique is much more direct, and though the Mount Washington observations were all made in cloud, the general similarity is striking.

6. Discussion

The wide range of values of C at which a mark is adjudged to be at the visual range (or rather at the "visibility distance") is, in the opinion of the authors, primarily the result of the instructions to the observers. These instructions demand the recognition of an object, rather than the detection of a boundary. Instead of a simple visual task they require a complex process about which very little is at present known.

The difficulty of this process results in undesirable attitudes. In the present investigation the experimenter detected a tendency for the observers to make up their minds about the "visibility" from a general glance at the landscape and then to choose a mark to justify this estimate. The other author can confirm this impression from the results of much earlier experience as an inspector of meteorological stations.

We have every confidence that instrumental errors cannot have contributed materially to the large spread of values. The error of a single measurement (which is really the average of ten or fifteen readings) may be estimated at ± 0.002.

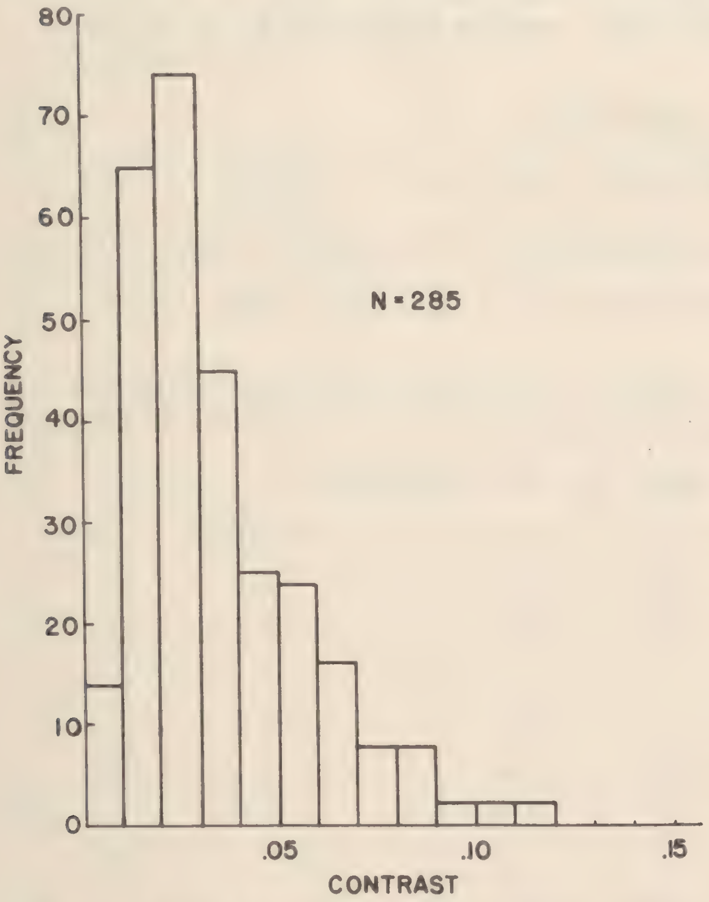


Figure 5. Frequency distribution of values of contrast calculated from the Mount Washington observations, 1943 - 1944.

It is evident that we must abandon the attempt to choose a value of ϵ by means of which the current estimates of "visibility" can be converted into information about the optical properties of the atmosphere. It is no wonder that the synoptic use of this element has found little favor.

What is needed is, of course, good instrumental measurements of σ. In the absence of these, the writers wish to make the suggestion that the official instructions be changed to require the use of a criterion of detection rather than of recognition. By the use of the Tiffany data, or more probably some similar data soon to be obtained,* it should then be possible to derive a reasonably good value of σ and consequently of the sighting range of objects of any area and contrast.

It is not hoped that such a drastic change in official procedure will be easy to bring about. To make its adoption easier, the authors wish to suggest an operational test, as follows: at some well-staffed and well-equipped airport (preferably furnished with instruments for measuring σ), several additional

*Private communication from Dr. H. Richard Blackwell.

observers should be set to make estimates of the visual range, using a criterion of detection according to carefully worded instructions. These observers should not be aware of the estimates or instrumental measurements made simultaneously by the regular staff. At the completion of a sufficient number of observations, the two (or more) sets of data could be inter-compared.

The results of the present experiments are essentially negative, in that they show the unreliability of the present estimates of "visibility". They may, however, have a positive value. While no reliable information about the optical state of the atmosphere seems to be obtainable from estimates of "visibility", it seems likely that our results might be applied to instrumental measurements of σ to give a distance V which would generally seem reasonable to the working meteorologist. The median of our observations is 0.030; that of the Mount Washington observations, so different in all their details, is 0.024. May we conclude, therefore, by suggesting $\epsilon = 0.030$ as a value for the conversion of instrumental readings into "visibility", but not on any account for the reverse process.

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TABLE I

Frequency of Observations of Contrast

Contrast	Frequency	Contrast	Frequency
0 - 0.009	20	0.100 - 0.109	8
0.010 - 0.019	152	0.110 - 0.119	18
0.020 - 0.029	218	0.120 - 0.129	5
0.030 - 0.039	206	0.130 - 0.139	8
0.040 - 0.049	125	0.140 - 0.149	7
0.050 - 0.059	81	0.150 - 0.159	5
0.060 - 0.069	65	0.160 - 0.169	1
0.070 - 0.079	37	0.170 - 0.179	1
0.080 - 0.089	22	0.180 - 0.189	1
0.090 - 0.099	19	0.190 - 0.199	1

TABLE II

Median Contrast for Each Mark for Which $N > 9$; also Number of Observations of High Contrast

Mark No.	Type	Angular Dimension		N	Median	No. of Times $C > 0.0895$
		Vert.	Hor.			
24	Building	1.5°	0.5°	20	.040	2
26	Evergreen trees	0.4	1.5	58	.035	3
33	"	0.8	0.4	10	.040	1
37	"	0.4	2.6	27	.065	8
2	Deciduous trees	0.4	8.	18	.030	1
d	"	0.8	10.	17	.026	2
K	"	0.5	10.	12	.026	1
e	"	0.4	10.	29	.030	0
4	Hill-top	0.6	1.4	22	.022	0
5	"	0.3	1.4	18	.024	0
9	"	0.6	7.2	51	.026	2
10	"	0.2	2.5	11	.027	0
11	"	0.2	2.0	23	.029	1
13	"	0.2	7.	34	.031	0
16	"	0.2	3.4	63	.031	2
25	"	0.1	0.7	57	.045	6
27	"	0.1	1.4	23	.043	1
29	"	0.2	4.	54	.037	1
34	"	0.2	1.	29	.030	3
36	"	0.2	2.6	17	.032	1

Discussion:

Dr. Neuberger commented on the obvious inadequacy of visibility estimates as indicated by Mr. Middleton's paper. Dr. Neuberger emphasized that the computation of meterological range is based upon the assumption that the contrast threshold of the eye is 2%. Since it is obvious from Mr. Middleton's data that the threshold is much greater than this, on occasion, computations of meteorological range are not on the safe side. Dr. Neuberger commented that in his opinion the large spread of individual data is due to the fact that meteorological observers have variable criteria. The excessive variability is believed to be due to the use of a recognition rather than a detection criterion.

Dr. Duntley commented that he considered Mr. Middleton's paper of considerable importance. Dr. Duntley stated that meteorologists measure many quantities with precision, visibility estimates being the worst of the many measurements made. Dr. Duntley emphasized his belief that visual estimates of visibility should be avoided and that physical measures of atmospheric clarity should be made. From the physical measurements of atmospheric clarity, it is possible to compute how far objects of interest will be seen on the basis of the Tiffany Visibility Forecasting Nomographs. These nomographs involve precise visual data measured in the laboratory. Physical instruments to measure atmospheric clarity exist and could be produced.

Dr. Hulburt asked if there is any evidence in Mr. Middleton's data that the threshold is higher when the atmosphere is less clear.

Mr. Middleton replied that meteorological ranges were encountered varying from 1 to 30 kilometers and that within this range there was no systematic change in threshold as a function of atmospheric clarity.

Mr. Douglas emphasized that visibility forecasting is even worse than Mr. Middleton's data indicate since the tendency is for the meteorological observer to average the visibility range in all directions. Furthermore, meteorological observers tend to report the same visibility again and again even though atmospheric conditions change greatly.

Mr. Middleton agreed that the observers in his experiment were better than average since they knew they were being studied.

Dr. Hulburt pointed out that the task of estimating visibility is a difficult judgment to make.

Mr. Douglas agreed that no one was criticizing the meteorological observers but rather the conditions of observation.

ANNOUNCEMENT CONCERNING

DR. W. DAVID WRIGHT'S VISIT TO THE UNITED STATES

"Professor Stanley S. Ballard announced that a fairly extensive trip to the U. S. is being planned by Dr. W. David Wright of Imperial College, London. Dr. Wright is well known to Vision Committee members as a vigorous worker in the fields of color vision, color measurement, eye movements, specification of the standard observer, etc. He will arrive in the U. S. on February 5 and will depart for home on April 16, 1952. He will visit quite widely in the eastern part of the U. S., going as far west as Chicago. Details of his trip are being arranged by Professor Ballard, who would be glad to inform interested persons of dates and places for which visits are planned. During his stay in this country, Dr. Wright will hold a Visiting Professorship in Optics at Tufts College, and will serve as Adolph Lomb Memorial Lecturer of the Optical Society of America."

ENGINEERING PSYCHOLOGY AT THE ROME AIR DEVELOPMENT CENTER, GRIFFISS AIR FORCE BASE, ROME, NEW YORK

John F. Corso

In June of this year, there was established at the Rome Air Development Center, Griffiss Air Force Base, Rome, New York, a Human Factors Office to aid in the solution of psychological problems related to the design and development of ground electronics equipment. The Office is directly responsible to the Technical Director of the Electronic Development Division of the Center. This staff arrangement permits unusual opportunities for pre-developmental consultation on equipments and systems that are designed by the laboratories and units of the Center. Moreover, close association with design engineers affords new insights for guiding research so that human factors data essential for evaluating future proposals may be on hand in time to be of use. It is still too early to know exactly how much can be accomplished by such a scheme which incorporates human factors research into a major developmental program, but some information about the organization, some examples of research undertaken and the broad plan of attack on problems can be detailed.

At present, this newly established organization, headed by Lt. Col. George E. Long, is divided into three sections: (1) a Displays Section, (2) an Equipment Section, and (3) a Systems Section. A plan has been drawn up so that the programs of the Office will integrate closely with the mission of the Center. This plan reduces the overall mission into six major problem areas and, for each of the six, shows the Rome Air Development Center projects and the Human Factors Office projects which contribute to each area. Through the analysis of the latter projects, a list of human engineering variables has been evolved and the action necessary to obtain specific information on these variables has been indicated.

A few specific examples will illustrate the kinds of problems referred to the Human Factors Office on the design and layout of equipments and systems: (1) the evaluation of a speech compression system for use in air-to-ground communications, (2) the evaluation of certain proposed projection systems for displaying radar information, (3) the design of plotting boards and automatic status boards for use in the Air Defense System, (4) the determination of the relative distribution of tactical information between plotting boards and status boards for optimal operational use, (5) the determination of operator capabilities in tracking targets on plan position indicators by means of appropriate control devices, and (6) the design of a warning-light system for indicating the malfunctioning of equipment in rooms containing numerous electronic units.

In order to obtain data on these and other problems, the Human Factors Office has undertaken a three-fold approach. First, a psychological laboratory is currently under construction to permit staff members to carry on both fundamental and applied research. Second, a contractual research program has been inaugurated and will be expanded to include additional universities and qualified private organizations. Finally, it is planned to engage consultants for short time periods on special problems related to the mission of the Center.

ALLEGED EFFECTS OF THE NEAR ULTRAVIOLET ON HUMAN VISION

George Wald*

(Paper in press, Journal of the Optical Society of America, 1952)

It has been reported that short exposures of the human eye to near ultraviolet radiation in the wavelength range 290-365 mμ produce appreciable changes in subsequent dark adaptation, and a lasting depression of visual sensitivity, rod and cone. These reports are hard to reconcile with the fact that only traces of such radiation reach the retina. Wavelengths shorter than 300 mμ are absorbed by the cornea of the eye, and there can do damage; longer wavelengths up to 400 mμ are absorbed in the lens.

The assertion that such radiations affect the visual sensitivity is re-examined in the present paper. Exposures to ultra-violet light identical with those referred to produce no appreciable effects on subsequent dark adaptation of the normal eye, rod or cone. In lensless (aphakic) subjects, near ultraviolet radiation in the neighborhood of 365 mμ does reach the retina and is clearly visible. Even in such persons, exposure to the near ultraviolet does not affect the threshold of rod vision after 20 minutes dark adaptation. The early portions of dark adaptation - the adaptation of the cones, and sometimes also the early rod thresholds - may be raised; but these changes are caused, not by intrinsic effects of the ultraviolet, but by the increased brightness to which it gives rise in the aphakic eye.

It is concluded that ultraviolet radiations which might harm the retina do not reach it. Those which reach the retina do it no harm, and can at most be seen.

Discussion:

Dr. Crozier commented that recent research has convinced him that the successive measurement of dark adaptation curves may involve an additional factor which is not usually considered to exist. It has been found that a second dark adaptation curve is different from the first even though pre-adaptation conditions are the same. Such an effect may be involved in some of the earlier work reported by Wolf in which it was concluded that ultraviolet radiation influences the form of the dark adaptation curve. Dr. Crozier commented that differences such as those reported by Wolf have been obtained not only when white light is used but also when violet light is used for the measurement of dark adaptation.

ON THE LIMITS OF STEREOPSIS

Kenneth N. Ogle
Mayo Foundation and Mayo Clinic

So far as I can discover, practically no quantitative data have been reported on the actual limits of disparity within which stereoscopic depth exists. The physiologists and writers in physiological optics of the last century have pointed out that stereoscopic vision exists even when the disparity between the images in the two eyes is so large that the images are seen double. However, if the disparity becomes too large then indeed stereopsis ceases. Most of the papers of the period deal with the problem of where the double images are localized, and this problem alone resulted in considerable controversy.

Suppose the eyes fixate steadily a point F. An object point P which lies at a distance farther than the fixation point from the eyes to the right, for example, has visual angles to the two eyes corresponding to the spatial separation F and P which are different. The geometrical disparity between the images in the two eyes is defined as the difference between these two angles, $\delta = \alpha' - \alpha$. The physiological disparity probably differs slightly from this. The object point must lie on the circle in order for the disparity to be zero.

Most of the reported experimental work dealing with spatial localization with double images could seldom avoid empirical motives for depth localization, such as, for example, a decrease in angular size of test objects, a change in brightness, the influence of surroundings, change in stimulus to accommodation, or the experiments were limited in extent to which large disparities could be introduced because of mechanical difficulties, or they involved very artificial conditions, as often found in the hand stereoscope.

The technique used in the preliminary data to be reported here avoids these empirical factors. The eyes again fixate a suitable point 50 cm. from the eyes. They see also by reflection a test object from specially treated half-aluminized mirrors. The mirrors, which are linked by suitable levers and a hand screw, can be turned about vertical axes in directions opposite to each other. The degree of turning is accurately indicated on a suitable dial. When the mirrors are turned a disparity is introduced between the images of the two eyes, symmetrical about the initial position, and stereoscopically the test object is then seen farther or nearer than the fixation point. By changing the angular position of the test object, the study of disparity can be made for any desired lateral visual angle.

Preliminary tests utilized a very slender vertical needle as test object, appropriately illuminated so as to give a brilliant narrow line about 1 arc degree in height. The fixation point was a small bright dot less than 1/2 mm. in diameter, mounted on a sheet of glass which was independently illuminated. Suitable apertures and backgrounds restricted the field of vision to the fixation point and test rod. The tests were conducted in a semi-darkened room the walls of which were painted black.

The mirrors could be continuously rotated in one direction or the other by a motor control. Accordingly, with steady fixation the disparity between the images is altered and the subject can observe the stereoscopic depth. This apparatus provides very wide ranges of disparities; the test object does not change brightness, or size, or result in a change in accommodation. Head movements are avoided by a suitable chin cup and a head rest.

The apparent behavior of the stereoscopic perception as the disparity is increased continuously in one direction can be described as follows.

From a position near the apparent frontoparallel plane, the test line appears to recede from (or approach) the observer, and the observer has a strong feeling of stereoscopic

depth or plasticity. His subjective impression is that the depth difference increases proportionally.

The test line then rather suddenly separates into two images, but the stereoscopic sense of depth continues to increase; the plasticity continues.

The increase in depth then rather suddenly stops, and the strong sense of plasticity fades, yet there is still a definite concept that both images are farther (or nearer) for quite a range of disparity. Then rather abruptly even this concept of farther (or nearer) than the fixation point no longer exists, and the two half-images seem to be indefinitely localized.

This behavior of the test as the disparity changes was tested in several different manners but mostly by the method of adjustment, which was used for

(1) Continuous observation of movement

(2) The images of the test line were momentarily exposed (about 1/2 second's duration)

(3) By suitable screening, one of the half-images could be occluded and then exposed briefly.

The limits of the two ranges of stereoscopic depth perception are indicated by the data shown in the table, for various lateral (peripheral) visual angles. The first set of data indicate the limits of disparity for fusion or where double images first appear. The next two sets are for the limits of a patent stereoscopic sense of plasticity, the lower one obtained by exposing momentarily one of the half images, and the upper one obtained by momentary exposure of both images. These two sets of data give the limits within which a conception of depth exists. The last set of data indicates the limits of disparity within which some sense of depth based on disparity exists.

It must be borne in mind that these limits are not sharply defined, and that a probability function of the occurrence of the phenomena exists at each.

There is little doubt that these limits also vary with experimental conditions, especially time of exposure, adaptation, etc., and with individuals. With continued observation of the double images, the plastic or depth effect may fade, a fact reported in the literature. Care must also be taken to avoid after-images, also.

With the method of exposing only one of the half images, it was found that near the limits of the two ranges, a suppression of the steady image would sometimes occur when the second image was exposed.

The equivalent spatial regions corresponding to the angular limits of disparity can be obtained by calculation. The spatial region corresponding to binocular single vision is small, as is also the spatial region of a patent stereoscopic vision at the point of fixation. The corresponding spatial regions increase very rapidly toward the periphery. Obviously then if eye movements are permitted from the one point to another within these limits, the effective sizes of these spatial regions are approximately doubled.

The existence of such a large range of disparities within which the perception of stereoscopic depth occurs is an important factor in binocular spatial localization, and may be as important as the stereoscopic acuity itself.

LIMITING DISPARITIES IN STEREOSCOPIC VISION

		Minutes of Arc Peripheral Angle			
		0°	2°	4°	6°
Patent Stereopsis	Fusion	7.5'	11'	19'	24'
	Stereo flash exposure	20'	60'	95'	130'
	Stereo half-image exposure	15'	38'	56'	75'
	Qualitative depth of double images	25'	85'	155'	220'

Discussion:

Dr. Rand asked what exposure time was employed in Dr. Ogle's measurements.

Dr. Ogle reported that exposure time was one-half second.

Dr. Sloan asked what the phenomenal effect was when the objects were moved beyond the point at which doubling occurred.

Dr. Ogle replied that the sensation obtained after doubling has occurred is a feeling of "plasticity" and a feeling that the images have moved back.

Dr. Rose asked to what extent the depth perception which can occur without fusion is helpful to a pilot.

Dr. Ogle replied that he believed it remarkable how much information we can get from the disparity angle in the case of doubled images.

SELECTIVE SPECTRUM LIGHTING

by

Dr. Max W. Lund, Mr. Donald W. Conover and Mr. John M. Stroud

1. Introduction

The use of CRT's as a means of displaying information for military purposes poses several problems in the field of Human Engineering. The human link is, at present, mandatory in the CIC or GCI systems. The success or failure of the system is dependent upon the ability of the human operator to discriminate targets from noise and to make adequate judgments concerning those targets.

Present practice in areas where CRT displays are used is to darken the room to a level which makes for effective reading of the scope without completely blacking out the area. This lighting level imposes severe limitations on other members of the CIC team, however, and precludes satisfactory maintenance during operation and makes the reading and writing of messages, etc., a rather difficult task. It was proposed that information concerning monochromatic sources, filters, and human vision be examined for a solution to the problem of ambient lighting in CIC and other areas using CRT displays. Monochromatic sources have been known for some time and information concerning filters for particular bands of wavelengths has also been available. It seemed reasonable to assume that if the proper combinations of monochromatic sources and filters could be found, a partial solution to the CIC lighting problem might be effected. Perusal of the literature and inquiries concerning filter properties of certain substances were made. As a result of this activity two systems, using line spectra and filters or phosphors to respond to wavelengths other than these bands, were developed. These will be described in the body of this report.

2. Ambient Lighting and CRT Displays

The visual system of the human is essentially a ratio sensitive system. In order for adequate discrimination of targets on a CRT to occur, the ratio of signal to "noise" must be sufficiently great to insure detection. Ambient lighting, which causes specular and diffuse reflections on the scope face, acts as "noise" in the system and tends to reduce the probability of detection. The maximum contrast in the present phosphors may be obtained during near black-out (0.1 ft. c) conditions. However, many other activities are also in progress during operation and a compromise is usually attained whereby sufficient ambient light is available to make possible these other activities. In addition, flashlights or other light sources are used where necessary. These are distracting influences in respect to the operator of the CRT and they tend to reduce the efficiency of the scope-man team in the system.

Present high speed aircraft, presenting a relatively small reflective surface, make the problem of detection in raw radar data a difficult one at best. If additional "noise" in terms of reflectance and illumination from the plotting surface and face of the CRT is introduced, the probability of detection is reduced accordingly. Failure to detect enemy targets from background noise, even for a matter of a half minute or so, could well be catastrophic in the case of the picket submarine and certainly this time lag reduces the effectiveness of air intercept systems where the CAP is only slightly superior in speed to the attacking aircraft. An analysis of the information needed, and the rate of flow of this information, for successful air interception clearly points up the importance of a CIC situation where the operator will have the least distraction from ambient lighting as well as increased contrast in the picture painted on the CRT. In addition, the ease of movement and readily visible controls, etc., for other CIC personnel makes for a smoother functioning team.

3. Selective Spectrum Lighting (SSL)

SSL is a system which makes possible the maintenance of relatively high ambient light levels in a CIC or other area, using CRT's without introducing interference in terms of specular reflection from the face of the scope which would reduce the efficiency of the radar display. This is accomplished by using a line source for ambient lighting in the general area while employing a filter which is sensitive to only that band of wavelengths produced by the line source. In effect, the ambient light is not present when the area is viewed through goggles composed of the filter, or when the CRT is viewed through a disc made of the filter material.

CIC areas have both illuminated area displays and self-luminous displays. The illuminated displays are of two kinds: Those that reflect light as a mirror (specular reflection) and those that re-radiate diffusely. The self-luminous displays have their own primary light source. These include back projection screens, edge lighted displays, etc., as well as CRT displays. Both types of displays are important to the successful operation of the CIC and accordingly must not be disturbed by the lighting within the area.

Two SSL systems have been demonstrated. Each has certain advantages and limitations in a CIC type area. These advantages and limitations will be discussed in connection with a description of the systems.

4. The Yellow-minus-Yellow System

This system of area lighting is accomplished by the use of a sodium vapor luminaire and the use of didymium filters over the eyes (worn as goggles) or over the CRT. Commercially available sodium vapor lamps have been used in demonstrations at the CIC school and in operations aboard the SSR Spinax. The lamps are available in sizes from 600 to 20,000 lumens. The 20,000 lumen lamp with an appropriate housing is adequate for areas as large as found in the CV type CIC. The 600 lumen lamp is adequate for the area aboard a submarine installation.

Only one class of filter appropriate for the purposes of the Yellow-minus-Yellow system is available. Didymium filters, produced by Corning Glass Works have the peculiar property of completely absorbing the energy in the region of the yellow line of sodium. The filter glass contains the oxides of two rare earths: Praseodymium and Neodymium. The crystalline lattice structure of these rare earths is such that a narrow band of wavelengths peaked at 590 millimicrons are absorbed but all other wavelengths are passed with only a moderate loss in transmission. Figure 1 shows the transmission spectrum of the didymium filter.

By illuminating the CIC area with a sodium lamp, it is possible to keep the ambient light level at approximately one foot candle while eliminating the ambient light from the surface of the CRT.

The advantages of the "Yellow-minus-Yellow" system are:

1. Light levels are attainable in the CIC which permit reading and writing of messages, inspection and repair of gear, free movement of CIC

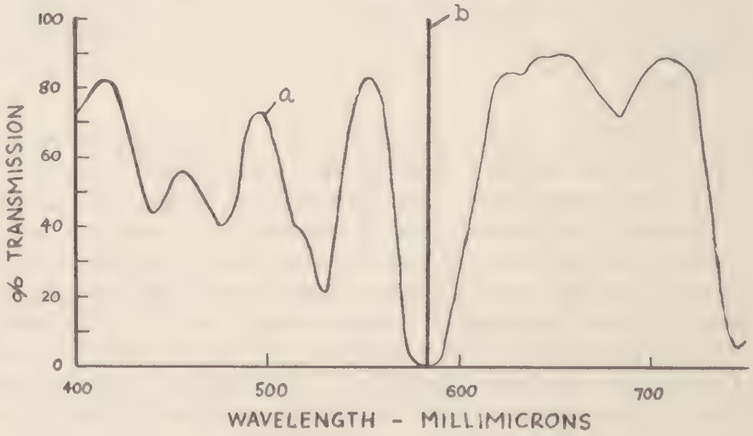

Figure 1. Schematic of yellow minus yellow system
a. Transmission spectrum of didymium filter
b. Sodium line

personnel, etc., which have heretofore been relatively restricted by the standard black-out conditions of operation.

2. The system is relatively inexpensive. The sodium vapor lamps are available commercially and the didymium filters may now be produced in quantity.

3. The system calls for no modification of present circuitry in radar repeaters or in the CIC. The sodium vapor lamp may be installed in appropriate places and driven by the a-c voltages now used aboard Navy vessels. The filters may be substituted for the top surface of the reflection plotter which is currently used with VK type repeaters.

4. The system is usable with present phosphors. All of the currently used phosphors have spectral distributions which, in the main, fall on either side of the lines of sodium.

5. Since the self-fluorescence of the phosphor is seen as against a black mirror, the contrast ratio of signal to noise is markedly increased.

6. The energy from the sodium vapor lamp can be used to excite fluorescing red and orange paints which can be used for color coding.

The disadvantages of the "Yellow-minus-Yellow" system are:

1. The system precludes dark adaptation.

2. Color coding on reflecting surfaces is lost in the area illuminated by the sodium vapor lamp. All colors from reflecting surfaces are seen as shades of gray. However, since the light level is at a relatively high level, small amounts of white light may be introduced, where color coding is necessary, without disturbing the radar operator. Also, as pointed out above, red and orange fluorescing paints can be excited by the yellow line of sodium and used within the CIC area. Plankian theory states that no wavelength shorter than the exciting source may be excited, so that in the Yellow-minus-Yellow system no fluorescing greens or blues are possible.

3. Some of the Yellow light is reflected from the didymium filter and may be a disturbing factor to the operator. He may see his face in the filter or see bright reflecting surfaces that are overhead. This reflectance may be reduced to where it is negligible, however, by the use of an Al coating or better, a coating of MgF_2 on the didymium filter. Where goggles are worn, the reflectance from the surface offers no problem.

4. The sodium line gives a deathly pallor to CIC personnel and therefore is unpleasant aesthetically. However, it is reported that adaptation to the yellow is reached in about twenty minutes. Reports from SSR spinax personnel indicate that there was some tendency to increased seasickness when in the yellow light but that this effect lasted only the first few days.

5. When the didymium goggles are used, the weight of the headgear is reported to be uncomfortable.

5. <u>The "Red-minus-Red" System</u>

A second possible use of a line source for ambient lighting and special filters and phosphors for use in SSL has been demonstrated. This system is somewhat more complicated and calls for certain modifications in equipment which will be discussed below. The system uses the line sources of the mercury vapor lamp with appropriate filters and a special phosphor in the CRT.

Mercury vapor lamps are obtainable from commercial sources, ranging in size from 600 to 20,000 lumens. The size of lamp needed varies with the area to be lighted but these sizes have been found to be adequate. Figure 2 shows the line spectra of the lamp It will be noticed that considerable energy from the lamp is in the ultraviolet and therefore deletorious to CIC personnel. This ultraviolet is removed by using a Noviol filter at the source. The main lines will be seen to fall in the blue and green with a minor line in the yellow.

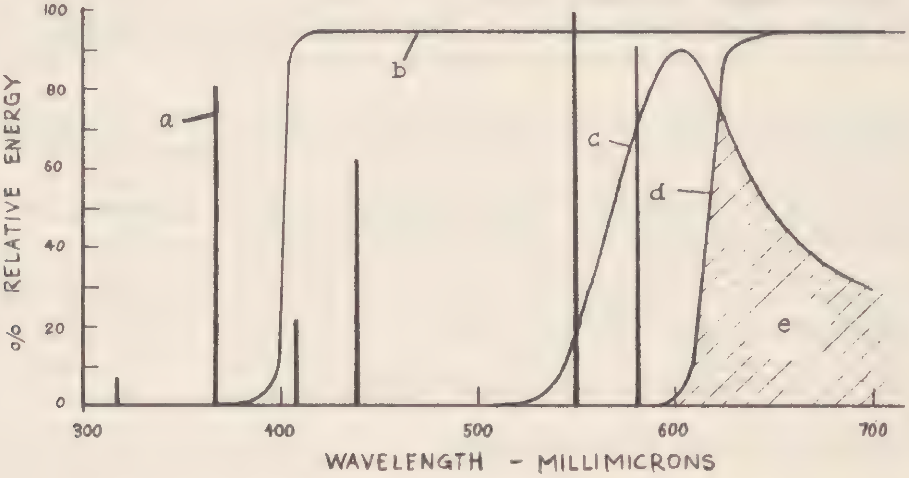

Figure 2. Schematic of red minus red system

a. Vertical lines 'a' show energy emissions of mercury arc
b. Noviol filter to remove ultraviolet at the source
c. Spectral emission curve of ''red'' British l.p. phosphor
d. Red filter over CRT to remove ambient illum. of mercury arc
e. Useable portion of the phosphor emission

Long persistent "red" phosphors are obtainable in experimental quantities at present but should be available in required amounts in the near future. The 1. p. phosphors first developed by the British have the property of fluorescing primarily in the red end of the spectrum (cf. Fig. 2). In addition to the color of fluorescence, the phosphor has two additional advantages for detection and tracking purposes. The usable persistence of the phosphor is approximately sixty seconds and there is no annoying bright flash as in the P7 phosphor. This "red" phosphor has many possible tactical uses in addition to its incorporation in the SSL system. For maximum efficiency of the phosphor, accelerating potentials need to be increased by roughly thirty per cent.

Two filters are required within the "red-minus-red" system. Noviol or a similar glass or plastic is used to filter the ultraviolet from the mercury vapor source. A red filter of which several are commercially available, is used to remove the ambient illumination of the mercury arc from the face of the CRT. The cheapest is probably Commercial Plexi-glass Red 160, a dyed methyl methacrylate resin which has been found to be quite adequate for the purpose.

Examination of Figure 2 shows that a mercury vapor lamp is used for the ambient lighting. The ultraviolet and the lines in the visible spectrum are compensated by use of appropriate filters. Since the mercury vapor arc illuminates the area with a minus red light, the "red" fluorescence of the phosphor is seen as though against a black mirror. As in the yellow-minus-yellow system, the contrast ratio of signal to background is greatly enhanced.

Advantages of the "Red-minus-Red" System are:

1. The area may be illuminated at a sufficient level to allow reading and writing of messages, free movement of personnel within the area, inspection and maintenance of equipment, etc., without disturbing the efficiency of the radar display.

2. The system is usable where dark adaptation is a consideration. By the use of suitable red goggles, dark adapted personnel (pilots, bridge and conning tower personnel) may enter and leave the CIC and read the displays while there without injury to their level of dark adaptation. Even turning the light on and off in the room causes little shift in the appearance of the indicators.

3. Color coding is possible since the mercury vapor lamp gives wavelengths in the blue, green and yellow and red fluorescent dyes can be excited by the shorter wavelengths of the source.

4. Because of the characteristics of the phosphor, increased definition is achieved on the CRT.

5. The phosphor has "memory" up to approximately sixty seconds which increases the possibility of detection and facilitates tracking.

Disadvantages of the "Red-minus-Red" System are:

1. The system requires modification of the circuitry of present radars to increase the accelerating potential for maximum effectiveness of the 1. p. phosphor.

2. The system calls for the replacement of presently used phosphors with the 1. p. phosphor.

6. Conclusions

1. Selective Spectrum Lighting employs line sources of energy in the visible spectrum form illuminating CIC areas and appropriate filters to remove these line sources of energy for the viewing of CRT displays. Laboratory and operational tests make it possible to draw the following generalizations concerning the use of selective spectrum lighting:

1. The ambient light level may be maintained at approximately one foot candle without disturbing CRT visibility.

2. Contrast ratios of the CRT presentation under selective spectrum lighting are considerably greater than those obtained under present lighting practices.

3. There is little loss of target detectability as a result of increasing ambient light levels as high as 10 foot candles.

4. Selective spectrum lighting systems may be installed immediately in CIC's with only superficial changes in equipment.

7. Recommendations

1. Improved selective spectrum lighting components should be developed.

2. Adequate color codings should be investigated for use in areas where selective spectrum lighting is installed.

3. The psychological effects on personnel working in areas illuminated with selective spectrum lighting should be investigated.

4. Selective spectrum lighting systems should be given further operational tests in representative installations.

Discussion:

Dr. Wald commented that if the eye uses light from a mercury arc, fluorescence occurs within the eyeball which leads to visual unpleasantness. This effect could be eliminated by use of an appropriate ultraviolet absorbing filter.

Col. Byrnes asked if the selective spectrum lighting had been tried on airborne equipment.

Mr. Conover replied that he did not believe that this had been tried but that he could see no reason why this system could not be applied to airborne equipment.

SEEING-FREQUENCIES AT RETINAL PERIPHERY

W. J. Crozier

(Abstract.)

1. This short communication records certain features of a somewhat elaborate investigation of the properties of the seeing-frequency function ψ (S), in relation to λ, for brief presentation of small images in the retinal periphery. The experiments here described involved chiefly the use of a square image 1. °5 on a side at the retina, centered 15° on the temporal side of the left retina of 1 observer. The exposure time was 0.0509 sec. Twenty-six sharply peaked bands (interference filters) between λ 385 and λ 712 were tested for the dark-adapted visual system.

2. There are two parameters, independently modifiable, of the "condensed" log-Guassian integral which, for exposure-times down to ca. 250 μ sec., effectively describes the form of ψ (S). These are its σ, and the abscissa of inflection. The latter (τ') corresponds loosely to the "average threshold" intensity (limits). The slope constant σ on the other hand measures the spread of the capacity to provide the response "seen." It refers to an essential property of action in the mechanism of excitation. This property is not subject to modification by the action of internal ocular filters, as is τ'.

3. At the fovea of the same eye of the same observer prolonged series of tests (Crozier, J. Gen. Physiol., 34, 87, 1950) have shown that $\sigma_{\log \Delta I_o}$ is a periodic function of λ. The interpretation was in terms of the participation of different specific sensitizers. This has been tested in several ways - by changing the concentration of O_2 inspired; by differential light-adaptation; by changing the image size. Variables employed include image area A, exposure-time, oxygen intake, and level of light-adaptation. The pecularities in the records of σ are correlated with data for other visual functions. The properties of τ' are specifically correlated with those of "threshold" data as customarily determined.

4. When a small image is briefly presented in retinal periphery, it is found that $\sigma_{\log \Delta I_o}$ smoothly declines from λ 385 to λ 509, then rises smoothly to λ 712. There is no sign of the multiple peaking obtained at fovea. Considered as o for excitabilities ($\log 1/\Delta I_o$) the curve is almost symmetrical, on a wave-number basis. At the blue side it follows with real fidelity the absorption of rhodopsin, but it is definitely too "broad" on the red side of λ 509. Either the degree of correspondence with rhodopsin absorption is fortuitous, - or else human rhodopsin, in the retina, has absorption properties different from those ordinarily described for this material. (Tests have been made, with polarized light, to examine the possibility that 2 forms of the sensitizer may be present. Thus far they have encountered serious difficulties of interpretation.)

5. The intensities for 50 per cent. seeing frequencies (τ') provide a curve which is not really smooth, but does adhere with excellent closeness to the course of other data on extra-foveal dark-adapted thresholds. The slight but definite irregularities on the $\tau' - \lambda$ curve are not contradicted by the light-threshold measurements.

6. Although the general course of σ vs. λ roughly parallels that of τ', and is therefore in sharp contrast to the behavior of σ at the fovea, it is still not possible to say that σ (or σ^2) is directly proportional to τ'. The dependent character of the changes in these

2 quantities is sharply exhibited in the fact that with progressive levels of light-adaptation τ of course increases, but (in the absence of photosensitization at <u>low</u> intensities of adapting light) $\sigma_{\underline{\log}\,\Delta\,\underline{I}_{o}}$ decreases to very small values.

This work, in its relation to experiments with flashes of much shorter durations, has been supported in part under ONR Contract N50ri-07642.

REVIEW OF MOTOKAWA'S WORK ON ELECTRICAL EXCITATION OF THE HUMAN EYE*

J. W. Gebhard

The Johns Hopkins University
Applied Physics Laboratory
Silver Spring, Maryland

* * *

INTRODUCTION

Much progress in visual science has been made by measuring the electrical response of the eye to a photic stimulus. In this connection, one need only point to the work of Granit (16), Hartline (18) and many others. Less deeply explored is the possibility of revealing some of the mechanisms of vision by using an electrical input to the eye and measuring the response in terms of the sensation of light such a stimulus evokes. Nevertheless, the fact that an electrical stimulus will easily produce a sensation of bluish-white light was discovered by LeRoy (30) in 1755, and has continued sporadically to interest physiologists and psychologists ever since. Visual perceptions caused by inadequate stimuli are called phosphenes and it was suspected long ago that the electrical phosphenes might be altered to some extent by photic stimulation. The first systematic work on this problem appeared shortly after it became possible to control electrical stimulation accurately. Electrical thresholds were measured at various levels of light adaptation and during the course of dark adaptation with conflicting results. Early investigators found no differences between light adaptation and dark adaptation (8, 28, 68), but later workers such as Verrijp (81), Achelis and Merkulow (2), Bogoslowsky (3), and Schwarz (75) have found the electrical threshold to be higher during dark adaptation. A new and perhaps very important turn has now been given to the problem of interaction between photic and electrical stimulation by Prof. Kōiti Motokawa and his associates at the Physiological Laboratory of the Tohoku University, Sendai, Japan. These workers have been ingenious in their use of the threshold of an electrical phosphene as a means of analyzing the effect of photic stimulation of the activity of the visual mechanism. In a rather formidable output of some 40 papers in the last four years, they have touched upon matters of brightness and color discrimination, color blindness, contrast, spatial summation, inhibition, flicker effects, visual illusions, and a new visual method of measuring fatigue. This is work of very great interest and represents a completely fresh approach to problems in the field of vision. There is no doubt that it will be followed closely by visual scientists. However, it is much too early to characterize firmly these researches. A great deal of experimental labor must be done before this is possible. Since Motokawa's work is too recent to be yet well known, it is the purpose of this paper to give a preliminary review of the main results of his experiments.

METHOD

The electro-stimulation method used by Motokawa is quite simple and is roughly the same for all his experiments. It differs in details from one study to another as research requirements change, but a statement of the general method here will suffice for most of the work.

*This report was prepared under Contract NOrd 7386 between the U. S. Navy, Bureau of Ordnance and The Johns Hopkins University.

Apparatus. The basic electrical equipment consists of a set of batteries, two flat electrodes, some kind of switch, a means of controlling the current passing through the tissues, and a method for measuring it. In addition to this, timers for producing pulses of variable duration, sine wave and rectangular pulse generators, and devices for delaying stimuli are used as required. Figure 1 shows the skeleton arrangement used. The auxiliary measuring interrupting and timing equipment connects into this basic circuit.

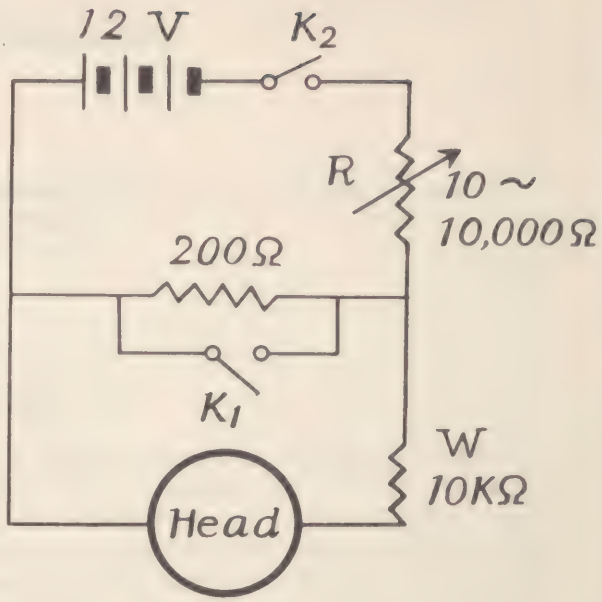

Figure 1. General stimulus arrangement used by Motokawa and his associates. Timers, frequency generators, etc., are connected into this or similar circuits. Here K_1 and K_2 are the switches of a spring rheotome set for delivering a single pulse.

The photic apparatus used by Motokawa is conventional equipment such as spectral light apparatus, filters, the Nagel adaptometer and anomaloscope, adapting screens, color tests, and similar well-known devices.

Procedure. The general procedure can also be broadly characterized for most of the work. The threshold of an electrical phosphene lends itself readily to measurement. It is, therefore, the threshold of this sensation that is used by Motokawa as an indicator of the effect produced by light stimulation. Two silver electrodes of about 2 x 2 cm. are fastened to the body by electrode paste containing NaCl. These are generally applied to the glabella and the occiput but sometimes the indifferent electrode is placed on the homolateral temple when only one eye is used. A weak, discrete stimulus current is then passed through the tissues and is increased or decreased in strength until a threshold phosphene is reported by the observer. The current must be interrupted, alternated, or given in pulses, since excitation occurs only on the make or break of the circuit. A continuous flow of current polarizes the tissues, and probably alters excitation; cf. Granit (15, 17), Gernandt (13), and Kravkov and Golochkina (26), but does not stimulate the eye. Measurement of the threshold current is made by a suitably sensitive instrument across a series resistance that is high in comparison with the tissues. This method is thought to ensure a constant intensity of current through the tissues for a given applied voltage.

The photic stimuli that are used are presented in a great variety of ways: at different intensities, at different wave lengths, at different places on the retina, at different times in relation to electrical testing, at different repetition rates, in different shapes, etc. The way the electrical threshold varies as the result of photic manipulation constitutes the bulk of the data presented by Motokawa and is the basis for his analysis.

Measurements. Data on the thresholds for electrically induced phosphenes are given in units of stimulus intensity required to evoke a just noticeable sensation. These may be expressed in either volts or amperes depending on the choice of whether voltage or current is measured. Stimulus current is generally thought to be the more suitable measure since variations of resistance due to changes in the tissues, sweating, and loosening of the electrodes are hard to control and may unduly affect voltage readings. It may perhaps be objected by some that Motokawa uses voltage. Nevertheless, he reports consistent measures, although in no case are enough data given to form an independent estimate of this.

Indeed, the main difficulty at present in a critical evaluation of the work is to determine the sufficiency of the evidence. Not only is little said about the number of measurements taken at a given stimulus value, little is said about the number of people measured.

Curves and tables are usually presented as typical examples of the results. In some situations one needs a few measurements on a lot of people, in others a lot of measurements on a few cases. Motokawa's experiments, in general, demand the latter. Whatever the case, statistical evaluation of the evidence at hand is not possible.

RESULTS

The results of Motokawa and his collaborators have been organized and presented under the following topics:

1. Excitability of the eye: effect of sensitization, adaptation level, time, position, intensity, etc.

2. Color discrimination: effect of wave length, intensity, color deficiency, color inhibition, microstimulation, etc.

3. Summation, contrast and optical illusions.

4. The strength-frequency relationship.

5. Measurement of general fatigue.

Excitability of the Eye

There has long been uncertainty as to how the electrical excitability of the eye is related to the normal adequate stimulus. One of the most persistent problems has been the decision of where, in the visual apparatus, the electrical stimulus acts. This is not the place to review the extensive material on this matter[1]. It will be sufficient merely to point out that a current passed through the eyeball is likely to be very diffuse in its effect and that the spread of stimulus current could reach anywhere in the retina or the optic nerve. However, if it can be shown that the presence or absence of light affects the electrical thresholds, some evidence for retinal involvement is indicated.

Sensitizing currents. A few of the earlier studies bearing on the problem of adaptation have already been mentioned. The first paper that came from Motokawa's laboratory in 1948 attacked this matter. Motokawa, Iwama, and Endō (62) studied the effect of an intermittent, subliminal electrical stimulus on the light threshold of the eye. They used 10% sub-threshold current pulses at 19 c./sec. during the course of dark adaptation that followed a five-minute pre-illumination to 10,000 lux[2]. Adaptation was followed for 40 minutes with a Nagel adaptometer. The results are shown in Figure 2 for both a 12^{o} area (A) and a 1^{o} area (B) with central fixation. The solid curve is for threshold sensitivity to light as normally measured. The dotted curve shows the results when the current pulses were used. The presence of an electrical current is shown in the data to produce an eye that is more sensitive to light. This appears true over both the rod and the cone portions of the dark adaptation curve.

Sensitizing light. The reverse experiment was also done: the electric threshold for just noticeable flicker phosphenes at 14.3 c./sec. was measured with, and without, thres-

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[1]The writer is in the process of preparing an historical account of electro-stimulation of the eye, running to 200 titles, which will appear soon.

[2]The lux, or meter-candle, is equivalent to 0.0929 foot-candles. Ten thousand lux, therefore, are 929 foot-candles.

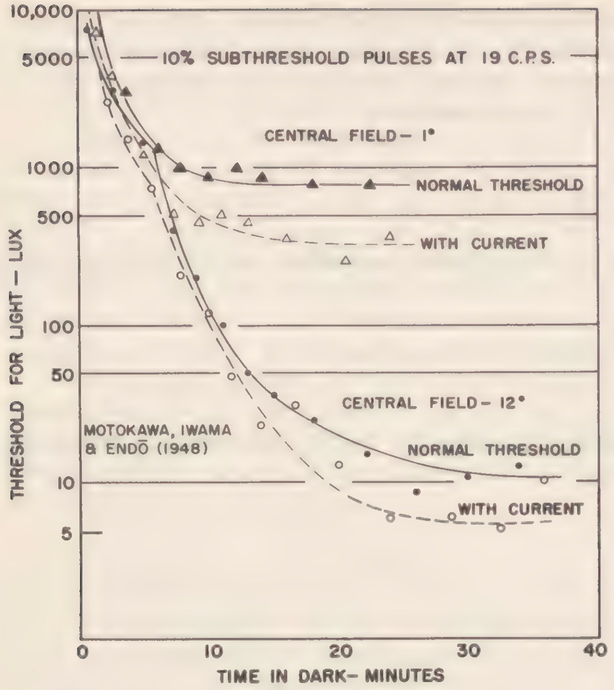

Figure 2. Effect of a subliminal electric stimulus on the photic threshold. After Motokawa, Iwama and Endō (62).

hold photic stimulation. Twenty-nine minutes of dark adaptation were allowed. The electrical thresholds continued to rise during the first 15 minutes of dark adaptation as measured both with and without light stimulation, and then leveled off. At all times, the electrical thresholds were lower in the presence of light.

This experiment clearly shows an interaction between electrical and photic excitation processes and suggests that something gets sensitized by electrical stimuli that makes it easier for light to act, and vice versa. However, it does not tell much about the site of electrical stimulation. The suggestion has frequently been made that the ganglionic cell layer of the retina is where the stimulus acts. This results from Iwama's finding that the chronaxy is too large to be accounted for as that of the optic nerve, vide infra (23), and that dark adaptation acts differently for electric and photic stimulation. Motokawa and Iwama (54) thought to come to closer grips with this problem by stimulating the eye with exponentially rising currents of various time constants in an effort to measure accommodation[3]. Three adaptation states were chosen: complete light adaptation to 10,000 lux, "moderate" light adaptation to a dimly illuminated white surface, and complete dark adaptation of about an hour. The presence of a threshold phosphene, as voltage was changed, was what was judged. The authors found that the value of Hill's time constant of accommodation (λ) was between 35 and 90 msec. for the completely light adapted state, 17.5 and 25 msec. for the "moderate" condition, and 45 and 320 msec. after an hour in the dark. Bouman (4) states that this time factor decreases with light adaptation and is about 4 msec. in light and 40 msec. during dark adaptation. These results are not easy to interpret and one can say only that neural events in the eye as revealed electrically are altered in some complex way by the presence or absence of light.

Chronaxy. More evidence of the same kind of interaction was reported by Iwama (23) in a study where he measured the time-intensity relationship of electrically exciting the eye under three different conditions of adaptation. These were somewhat as before: 950 lux for the light condition, about three lux for the moderate, and after 40 minutes in the dark for dark adaptation. Average chronaxies for these three conditions were 6.2 msec., 30.8 msec., and 13.8 msec., respectively. Such large chronaxies are not characteristic of muscle and nerve tissues and are considered by Iwama to be too large to be attributed to the optic nerve. He is of the opinion that his values result from stimulating the ganglion cells of the retina. Iwama's chronaxies are much larger than those of 1-3 msec. measured by the Bourguignon school (5) but are somewhat in closer agreement with Verrijp (81).

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[3]When a stimulating current is applied to a nerve tissue, excitability, after reaching a maximum value, tends to return to its initial or resting state. This effect is known as accommodation. If a current is increased very slowly accommodation will act to prevent the threshold from ever being reached. Accommodation is complete when excitability returns to its resting value with the continued flow of a constant current. This occurs in some tissues. In others, it does not return at all. This latter is the case of no accommodation. Where there is no accommodation, a nerve will continue to give responses as long as the current flows provided the intensity is of threshold level. The eye, incidentally, shows rather good accommodation as evidenced by the fact that a flash occurs only on the make and the break of the stimulus current.

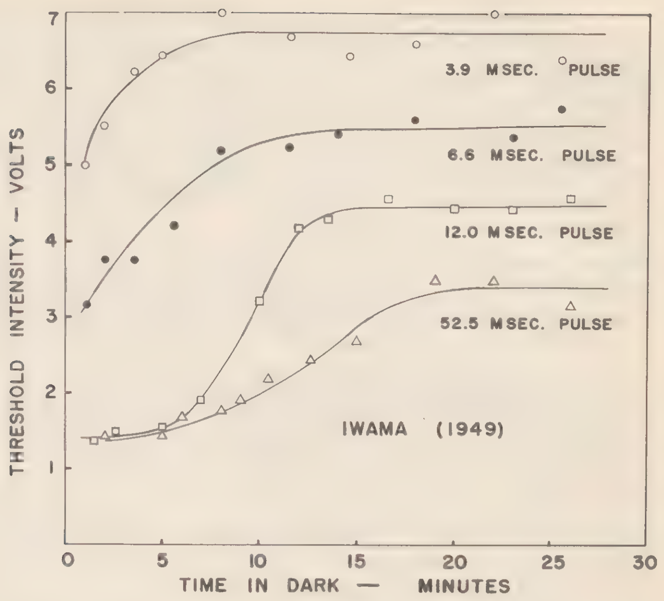

Figure 3. Effect of dark adaptation on the threshold of phosphenes due to electric pulses. After Iwama (23).

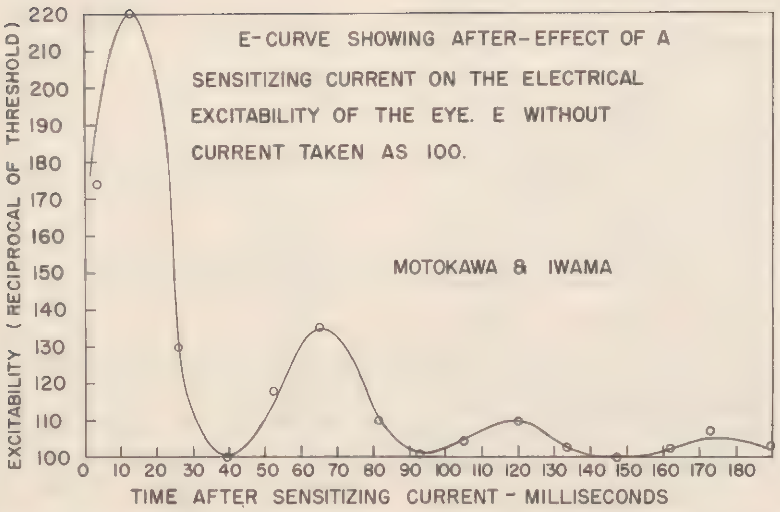

Figure 4. E -curve showing the increased electrical excitability of the eye after a sensitizing current. After Motokawa (38).

Use of pulses. Iwama also followed the change of electrical thresholds during the course of the first 25 minutes of dark adaptation. He used, for this, rectangular pulses of different durations. Here it was found that the thresholds rose for a few minutes after the onset of dark adaptation and then reached a constant value at times that depended on the duration of the pulses. This is seen in Figure 3. The shorter the pulses, the earlier the leveling off occurred. With 3.9 msec. pulses, no change in threshold was observed after about 10 minutes of dark adaptation. Stimulation with pulses of 52.5 msec. duration delayed this effect until about 20 minutes. In addition, Iwama stated that the chronaxy, during dark adaptation, passed through a maximum value at about 12 minutes. This again shows, in a general sort of way, that there exist, somewhere in the visual mechanism, a number of interacting factors that relate photic and electrical excitation.

Supernormal excitability. Motokawa (38), in a detailed account of periodic excitability of nervous tissue, referred to a paper by himself and Iwama (53), in which it was demonstrated that a subnormal electrical stimulus left in its wake an excitatory state that subsided like a damped oscillation.[4] This is shown in Figure 4 as an E- or "excitation"-curve. The ordinate is the reciprocal of the threshold intensities of electrical test stimuli given at spaced intervals. The abscissa is time after a subthreshold sensitizing current has been delivered. In this curve, the value without the sensitizing current is considered 100. The amplitudes of such oscillations as these depended upon the adaptation state of the eye and were found to be largest for a moderately light-adapted eye. This finding led Motokawa to suspect that photic stimulation might also leave the same kind of excitatory state (39).

The investigation of this possibility consisted of dark-adapting the eye for about 20 minutes. Then light exposures of from one-fifth to 2 seconds were given, followed by tests of the electrical threshold after a variable delay. The exposures were to white light at 70, 1.1, and 0.06 lux and the thresholds were determined with constant current rectangular pulses of 57 msec. duration. The data are shown in Figure 5, where the abscissa is elapsed time after pre-illumination and the ordinate is the reciprocal of the electrical threshold in percentage of what it was before illumination. The pre-illumination excitability value is taken as 100. It is seen from this curve that the eye becomes maximally excitable at about two seconds after the cessation of white light. The time at which the crest in these curves was reached was independent of the intensity of the pre-illumination. It was also independent of the duration of the pre-illumination, at least at the fovea (49). If this test is made with a light stimulus, the sensitivity of the retina was, of course, always found to be lower. Motokawa again proposed that the probable locus of the electrical

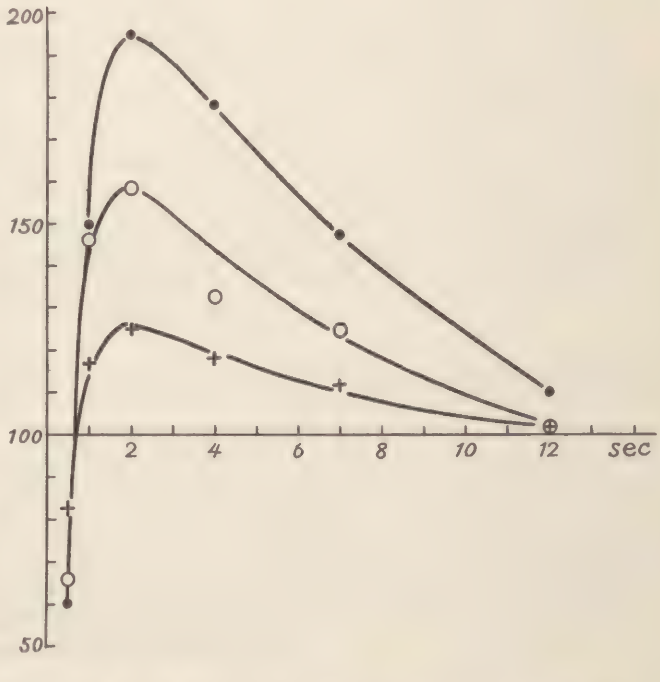

Figure 5. E -curve showing the increased electrical excitability of the eye after a sensitizing light. Upper curve 70 lux, middle curve 1.1 lux, lower curve 0.06 lux. Ordinate: excitability, pre-illumination value taken as 100. Motokawa (38).

[4]Motokawa refers again to this effect in a later paper (44) where a sensitizing current that was 80 percent of threshold was used. Oscillations at 18 c./sec. were observed that die away in amplitude. Certain other complex frequency relationships relating to this phenomenon were also reported.

effect is the ganglion cells of the retina. He pointed out that the decay of an electrical sensitization process is very rapid (200 msec.), whereas the aftereffects of a photic process persist for 10 sec. or more. This difference he attributed to the involvement of photochemical reactions, and argued that if the optic pathways or higher centers were responsible, light and electricity, as sensitizing agents, should behave in the same way.[5] He added further evidence of this by illuminating one eye only, but measuring the thresholds in both. The result showed that the enhanced excitability occured only in the illuminated eye.

Retinal position. It will be noted that Motokawa's method has by now taken on a distinctly analytical cast. In this same paper he tested further the versatility of electrostimulation as a research tool. He chose as his measure electrical thresholds taken at the crest point on the enhancement curve; that is, measured two seconds after the cessation of pre-illumination. He then pre-illuminated the retina with a 2° circular spot of 287 lux at different positions on the retina. Results for the left eye are shown in Fig. 6.

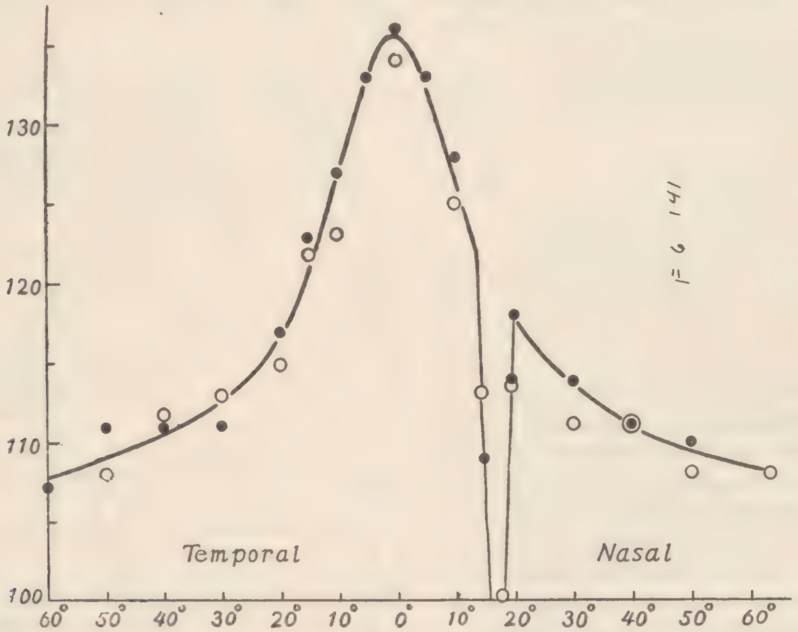

Figure 6. Effect of retinal position on increased excitability after pre-illumination to 287 lux. Ordinate: excitability, pre-illumination value taken as 100. Motokawa (39).

Sensitivity is enhanced most at the fovea, is zero at the blind spot, and falls off markedly toward the periphery. Figure 7 shows the same measurements for an electrical excitability following the use of a near-threshold intensity of pre-illumination. Curve A (solid) is the electrical data. Curve B (broken) is sensitivity to light as measured with an adaptometer. The curves agree remarkably well.

Intensity of pre-illumination. The next step was to determine the effect of the intensity of the pre-illumination on the electrical excitability of the eye (59). The test

[5]Another difference between electrical and light stimulation is that flickering phosphenes can be experienced to frequencies of intermittent current up to 80 c./sec. or more (31). This is far above the fusion frequency for light and appears to be due to the absence of the chemical reactions that must operate in the case of light.

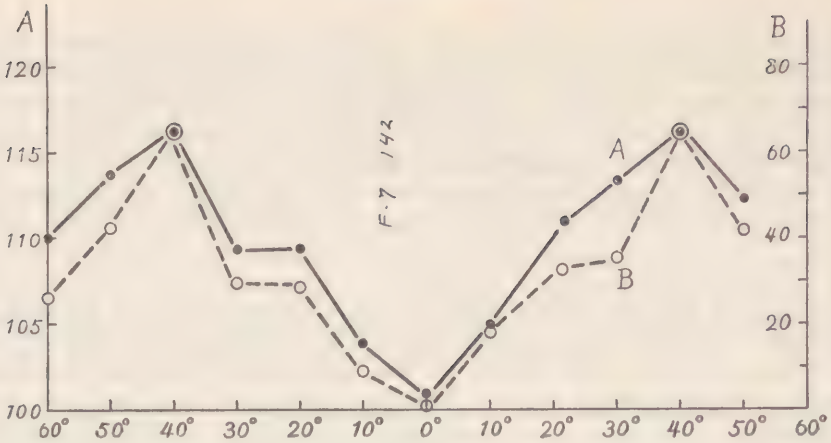

Figure 7. (A) Effect of retinal position on excitability afer pre-illumination at a near-threshold intensity. (B) Sensitivity to light as measured with an adoptometer. Motokawa (39).

current was confined to the illuminated eye by using electrodes above the eye and at the outer angle. The test pulses were 100 msec. in length. The size of the pre-illuminating test patch was 2° for observer K. I. and 8° for K. M. It was centrally fixated. The measure ζ plotted against log I for two Os is given in Fig. 8. A word of clarification is in order here, as this symbol will be used frequently in the discussion to follow. The measure ζ is defined as

$$\zeta = \frac{E - E_o}{E_o} \times 100, \text{ where } \underline{E_o} \text{ is the}$$

excitability, or reciprocal of electrical threshold, as determined in the dark after 20 minutes of dark adaptation, and E is excitability as determined after pre-illumination has ceased. The quantity therefore, is the increase in electrical excitability due to light over the electrical excitability in the dark expressed as a percentage. Twenty minutes of dark adaptation were chosen for the base E_o, inasmuch as the threshold to electrical pulses was shown by Iwama to be constant by then (23). We may now return to Fig. 8 in which the second curve is displaced to the right two log units. The dotted curve is attributed to the rod function since the 8° area covered more than the fovea in K. M.'s case.

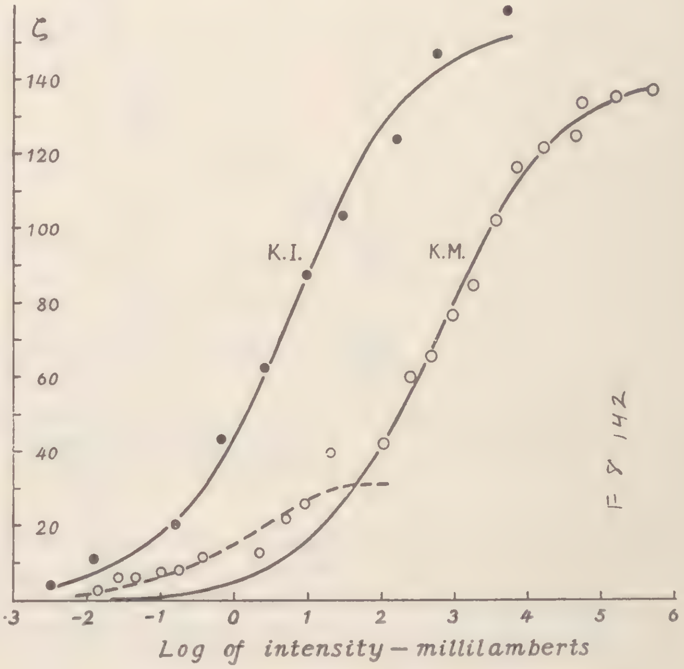

Figure 8. Effect of intensity of pre-illumination on excitability. Ordinate: ζ is the percent increase in electrical excitability due to light over what it was when measured in the dark. Motokawa and Iwama (59).

It was pointed out that the data obtained in this experiment bore a marked similarity to those obtained when CFF and visual acuity are plotted against light. Hecht (20) had shown that certain visual phenomena could be reasonably well described by the equation $KI = x^n/(a-x)^m$, where I is the light intensity, x the concentration of the photolytic substance in the stationary state, a is the initial concentration of the photosensitive substance, K expresses the ratio of the

velocity constants of the light and dark reaction, and m and n are numbers characterizing the order of the light and dark reactions, respectively. Motokawa proceeded to relate his measure ζ to this formula by substituting it for x and the solid curves shown in Fig. 8 were computed by this means, m and n both being taken as 2, as in Hecht's case. Motokawa had suggested in the previous paper (39) that a chemical or photosensitive substance was involved that raised electrical excitability as a consequence of light action. The success of using Hecht's equation, he felt, added convincing evidence for it.

Outside the fovea, the sigmoid relationship between ζ and intensity consisted of two segments that became more distinct the farther from the fovea the measures were taken. Figure 9 shows the results of measurements taken with a 2° pre-illuminating patch at the fovea, and at 5°, 20° and 50° removed from it. Motokawa concluded that the slowly rising portion of these peripheral measures for low intensities represented rod function, and the steeper portions at high intensities were due to the cones. In any case, satisfactory descriptions of this and the preceding data were obtained by substituting ζ in Hecht's equation to obtain

$$KI = \zeta^2 / (a - \zeta)^2.$$

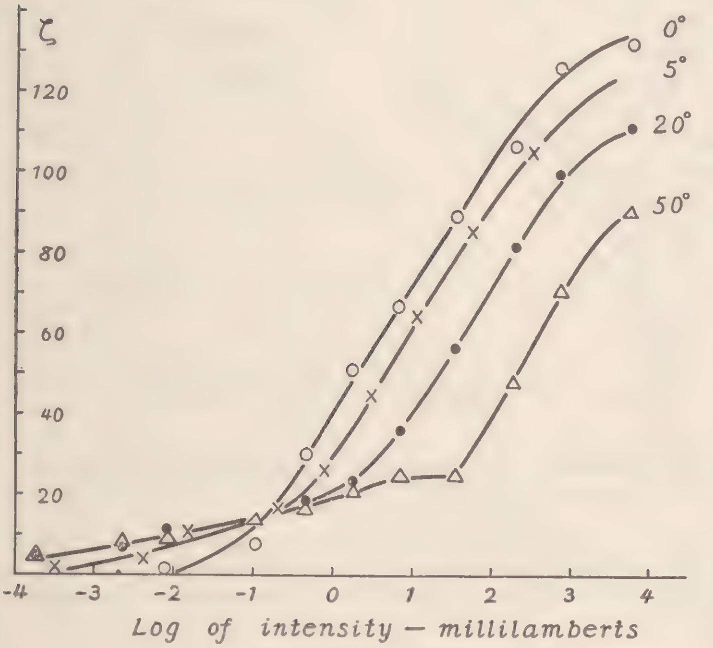

Figure 9. ζ -log I curves for pre-illumination at different retinal positions. Motokawa and Iwama (59).

Instantaneous thresholds. The work on the time-course of excitability following pre-illumination so far reported had not included measurements at delays shorter than about one-quarter of a second. Since it was indicated that a short subnormal excitability period existed before the rather lengthy supernormal period, Mita, Hironaka and Koike (33) investigated the region between the time when pre-illumination ceased and 2.0 sec. Except for more elaborate timing equipment for controlling the duration of the pre-illumination exposure and the introduction of the test stimuli, the method was as already described. A 1.5° circular field of light was used. The results were expressed in terms of ζ for 140 msec. test pulses and a representative sample is shown in Fig. 10. Part A shows the effect of intensity for an exposure of 1/250 sec. It is first to be noted that at all intensities the value of ζ is negative (subnormal excitability) for about 0.75 sec. It then rises to a maximum at about 2 secs. as had previously been shown. In addition, the finding was verified that the maximum value reached by ζ increases with intensity of pre-illumination. During the subnormal period, however, the reverse occured. The lowest values of ζ are reached when the highest intensities are used. The lower part of this figure shows what happens when intensity is held constant and the exposure time is varied. The highest supernormal values of ζ are reached with long exposures. The results for the subnormal period are confusing, although there is an indication that the length of the subnormal period may be inversely related to the length of the light exposure. The authors attempted to make something theoretical of this, but since they give no information on how much data they are treating, the importance of the rather detailed statements about supernormal and refractory periods cannot be judged.

"Empfindungszeit." Bearing upon another aspect of the general problem of the

excitability of the retina is a rather uncertain paper by Hironaka (22). He pointed out that the problem of where the electrical stimulus acts in the eye is still unsolved and proposed the comparison of the "Empfindungszeit" for a photic and electrical sensation as a means of settling the matter. The "Empfindungszeit" (E. Z.) was proposed by Fröhlich as a term for the time required by a stimulus to evoke a sensation (10). The photic E. Z. had been measured by Mita, Hironaka and Koike (34) for different conditions of adaptation and different retinal positions in a previous contribution. Hironaka employed the same method for the phosphenes and reported that E. Z. s for light at the fovea varied from 67. 5 to 185 msec. depending on the light intensity, and for phosphenes in the dark-adapted eye from 68. 5 to 176. 8 msec. depending on the current. These agree well. E. Z. s 50° on the periphery, however, were about 358 msec. for light. Since this is about twice the E. Z. for the phosphenes, Hironaka related the foveal light E. Z. with the effect of electrical stimulation and assumed that the electric excitability and speed of reaction of the cones is higher than that of the rods.

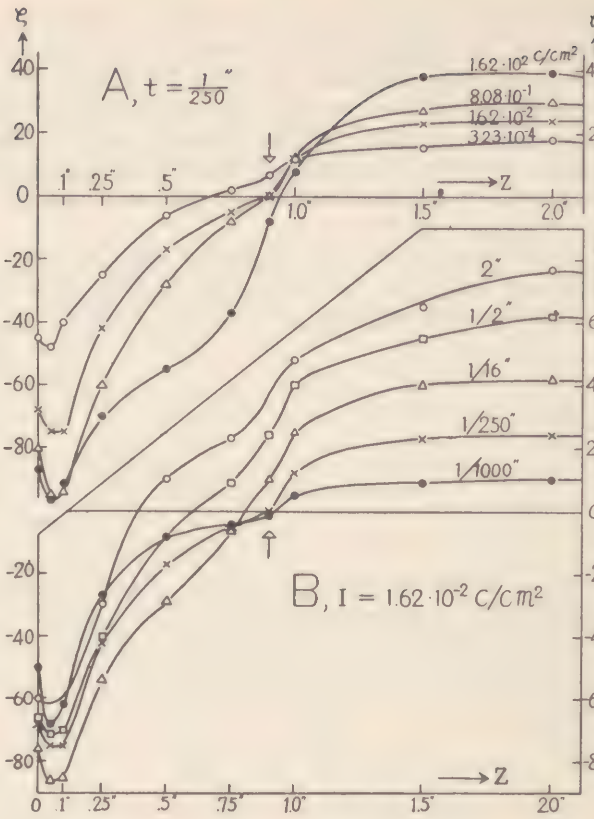

Figure 10. ζ -time curves for the period immediately after pre-illumination. Mita, Hironaka and Koika (33).

It is not completely clear that this is the case, although there is much evidence that the scotopic process is slower than the photopic. The fusion frequency for light is lower in the peripheral retina than in the central region, and dark adaptation proceeds slower in the rods than in the cones. In addition, Motokawa and Ebe (49) have presented data to show that the rod process, as determined by the ζ -time method, is the slowest in the retina. On the other hand, work by Bourguignon and Déjean (5) and Kleitman and Piéron (25) shows the speed of response of the cones to be less than that of the rods, whether measured by light or electrical stimuli. Whatever the case, the problem of measuring the speed with which sensations and perceptions are aroused has always been a knotty one and it is not surprising that agreement has not yet been reached.

Color Discrimination

The results of the physiological aftereffects of brief illumination with white light suggested, quite naturally, that a similar examination be conducted with colored lights. The time-course curve that showed the retina to be at maximum excitability 2 min. after the termination of neutral pre-illumination might well be of different shape with selective stimuli. The method used to investigate this aspect of the problem was the same, in the important details, as has been described for the white light studies.

Hue and the time-course of electrical excitability. In the first study of this kind

reported by Motokawa (40), both filtered light and monochromatic light from a dispersion spectrum were used. The pre-illumination was a spot of 2° exposed for one-fifth second and the electrical testing was done with 100 msec. pulses. Samples of filtered light data for three different subjects are shown in Fig. 11. The filters used were red (620-740 mμ), green (490-550 mμ) and blue (410-490 mμ). It is to be noted that the sets of curves differ markedly in shape. This matter of striking individual differences suggests color anomalies in vision, a problem to be taken up in the next section. But of primary interest at the moment is the fact that the maxima of the red, green, and blue curves are reached at different times; namely, at about 1, 2 and 3 sec., respectively. The white curve, shown in the upper part of the figure, corresponds to the green maximum except for amplitude. Figure 12 compares foveal with peripheral pre-illumination for filtered lights. Here it is seen that the ζ -time curves taken at 40° out on the periphery are very nearly the same for all hues and that in each case the maximum occurs at two seconds. The interest here for color theory is obvious.

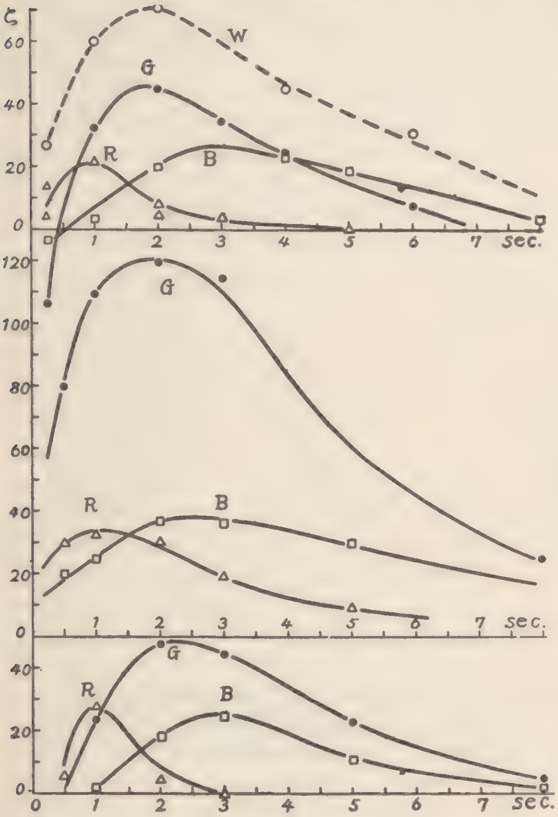

Figure 11. ζ -time curves for the normal eye with red, green and blue lights obtained by filters. Three different subjects. Motokawa. (40).

Effect of intensity. This is shown in Fig. 13 for spectral lights of 650, 585, 530 and 470 mμ. It is apparent from the curves that the maximum of any given wave length undergoes no shift in time as the intensity is reduced. It seems to be a property of the wave length alone. The yellow light affords a slightly later maximum than the red and lies between the red and green at about 1.25 - 1.50 sec.

Motokawa emphasized in this paper that time in these curves concerns the rate of the recovery process of the retinal physiological mechanism after illumination: the longer the wave length, the more rapid the recovery is. Intensity concerns the magnitude of physiological process but not its rate. Time and

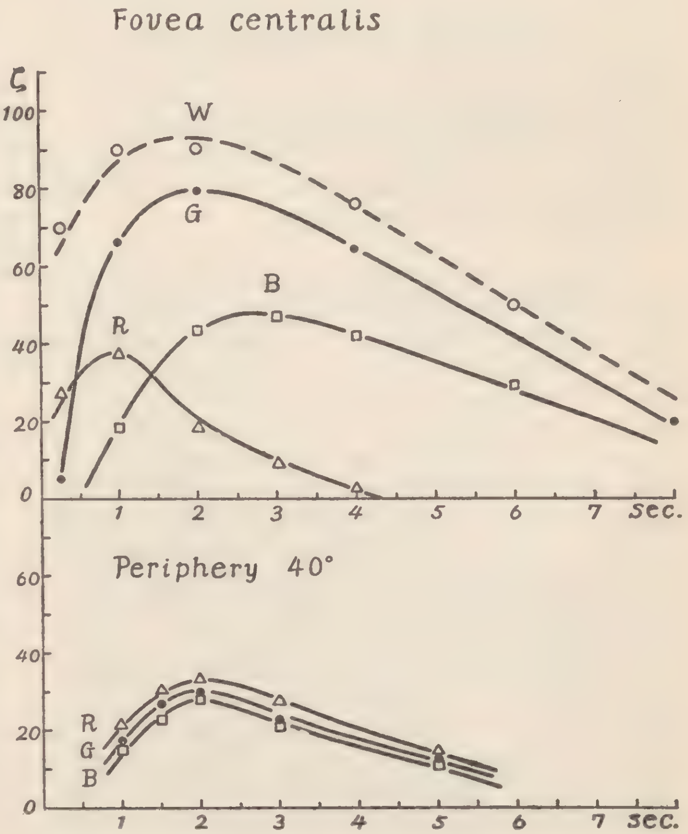

Figure 12. Effect of retinal position on ζ -time curves for the normal eye with red, green and blue lights obtained by filters. Motokawa (40).

intensity, therefore, are shown by the data, to be independent.

Wave length and the maxima of the ζ -time curves. The times after pre-illumination at which the maxima of the ζ measure were reached were investigated by Motokawa (42) for spectral light of different wave lengths. It was found that the time, (τ), at which the maxima occurred, varies with wave length (λ) as shown in the upper curve of Fig. 14. Time (τ) varies between something over three seconds for light of 400 mμ and about one second for light of 700 mμ. The curve connecting these two extremes is not smooth and τ changes rapidly with respect to λ in several places. The next curve shown in Fig. 14 is for $\Delta\tau$ and was obtained by conventional methods of measuring hue discrimination. The data are for Motokawa's eye and show minima at 460, 490, 585 and 630 mμ. Finally the curve $\Delta\lambda \backslash \Delta\tau$ was obtained by plotting the decrease of wave length $\Delta\lambda$ corresponding to the reciprocals of the slope of the τ curve against λ. This curve corresponds reasonably well to the hue discrimination function and is taken to be further evidence that a basic physiological process is being tapped by the electrical method. Once more it was asserted that this mechanism is peripheral and lies in the ganglion cell layer of the retina.

Color deficiency studies. The foregoing success in isolating distinctive patterns of electrical thresholds for selective illumination of the retina next led to an important question: What can be learned from color blindness? The method used to examine persons of deficient color vision was the same as has been described for preceding studies on the determination of the ζ -time curves. Figure 15 from Motokawa (43) is the excitability curve of a deuteranomalous subject measured after pre-illuminating the center of the eye with white light. Three maxima appear at times corresponding to those obtained by applying red, green and blue lights separately to a normal eye. A normal trichromat, if will be remembered, manifests only one maximum to white light. Motokawa noted that for the deuteranomalous case the more weakly excitable G curve dropped out rapidly as intensity was reduced. He felt that he had here basic physiological evidence of the three independent processes assumed by the three-components

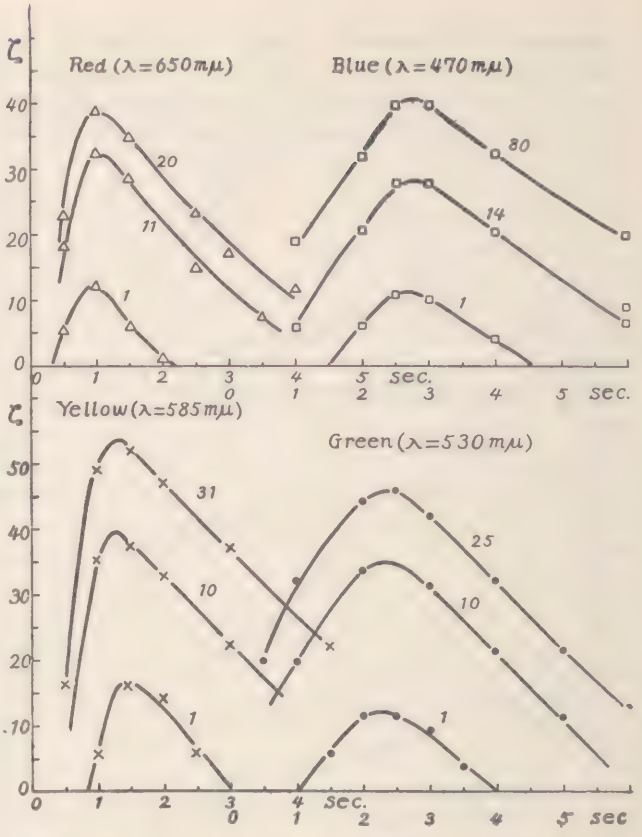

Figure 13. Effect of intensity of spectral lights on ζ -time curves for the normal eye. Numbers on curves are intensities relative to threshold intensity at the fovea taken as 1. Motokawa (40)

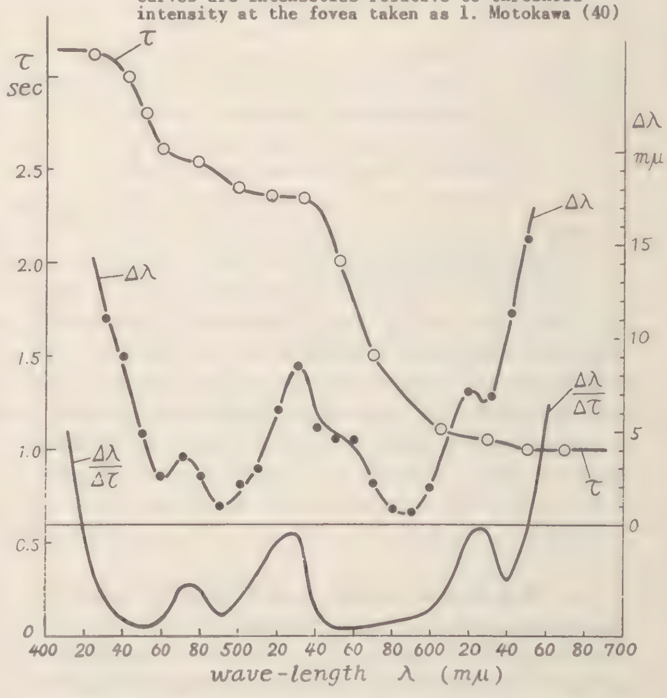

Figure 14. Upper curve: the time (τ) at which the maximum for ζ occurs for each wave length (λ). Middle curve: conventional hue-discrimination. Lower curve: the change in wave length ($\Delta\lambda$) corresponding to the reciprocals of the slope of τ for each wave length (λ). Motokawa (42).

theory of color vision. More evidence of this same kind is given by data presented in later papers by Motokawa (35, 36), Motokawa and Suzuki (65) and Ebe, Isobe and Motokawa (9) where the method was extended to measurements on deuteranopes and protanopes, as well as normal eyes measured when pre-illumination was presented outside the fovea. Figure 16 from Motokawa (35) shows a further analysis of what happens in the deuteranomalous eye and compares it with normal color vision. For the normal eye, light of different wave lengths produces maxima in the ζ-time curve that are progressively displaced forward in time as wave length is shortened. This fact has been discussed in the preceding section (42). Motokawa assumes here that the continuous curve of white light is a composite of the individual curves that result from selective stimulation. For the deuteranomalous case, however, the resulting family of curves reveals excitability maxima that at all times reflect the weakness of the underlying physiological G process. For white light these sensitivities fuse into a composite ζ-time curve with three maxima.

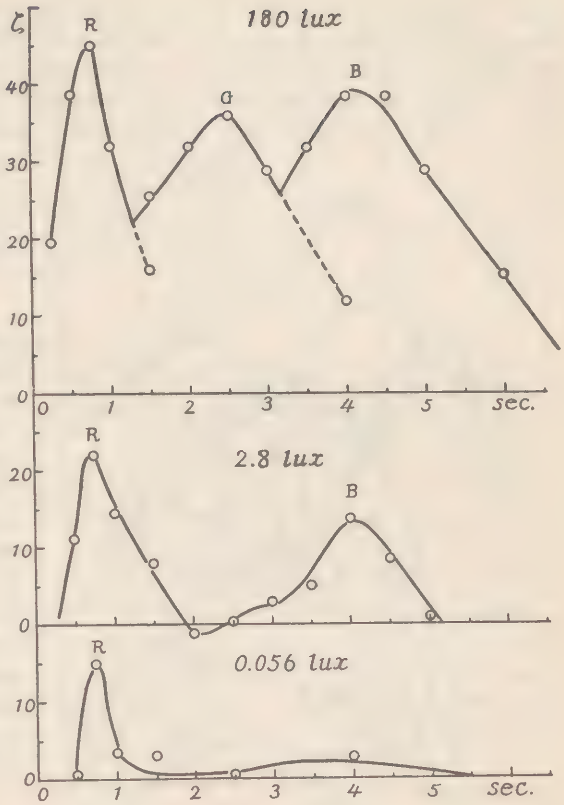

Figure 15. ζ-time curves for the deuteranomalous eye obtained with white light. Motokawa (43).

To show the effect of retinal position, Motokawa stimulated the normal eye extrafoveally at 5°, 10°, 15°, 25°, 35°, 45° and 50°. The pre-illumination was a 2° patch of white light. The results are shown in Fig. 17. At 5° and 10° a curve of three humps is seen. This is taken to be indicative of deuteranomaly in the parafovea of the normal eye. Further out the R and G both drop out leaving maxima corresponding to the Y and B. Up to this point the electrical findings correlate with what is found in ordinary perimetric studies. At 50° a ζ-time curve results showing a single maximum at 2 sec. The nature of this residual excitation curve is thought of as a rod mechanism.

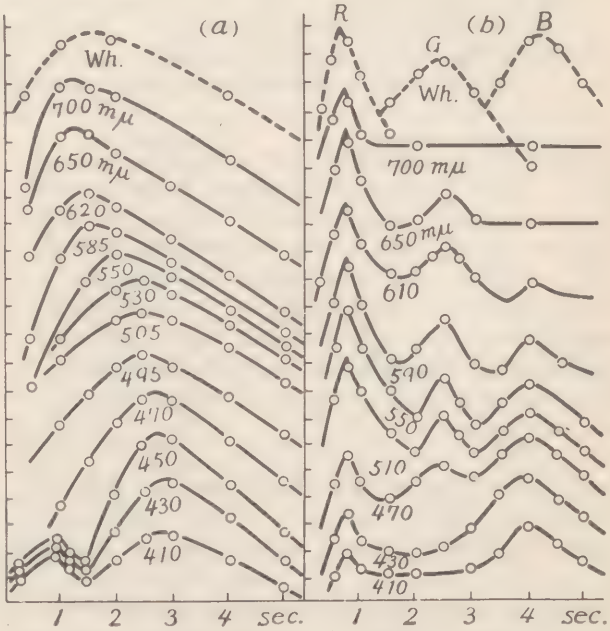

Figure 16. Effect of wave length on the ζ-time curves of normal (a) and deuteranomalous (b) eyes. Motokawa (35).

Physiological sensation curves. In a further attempt to isolate the nature of the basic physiological processes in vision by electro-stimulation, Motokawa (35) performed a very interesting experiment. He had previously determined the times after pre-illumination at which the maximum of ζ occurred as a function of wave length. Now he explored wave length, using the three times at which the maximum to red, green and blue light occurred. These were taken as 1, 2 and 3 sec., respectively. Figure 18 shows how ζ varies with wave length when measured at these times. Motokawa called these

"physiological sensation" curves and pointed out their striking similarity to those classically obtained by color mixture. He then proceeded to use this method of analysis on normal and deuteranomalous eyes at different positions on the retina: 0° (fovea), 15°, 25° and 35° (36). For the normal eye, in addition to using times of 1 sec. for R, 2 sec. for G and 3 sec. for B, 1.5 sec. for Y was also used. For the color-deficient case these time values were: 0.75 for R, 1.5 for Y, 2.5 for G and 4 for B. The results for each wave length are shown in Figs. 19 and 20 for the trichromat and deuteranomalous cases, respectively.

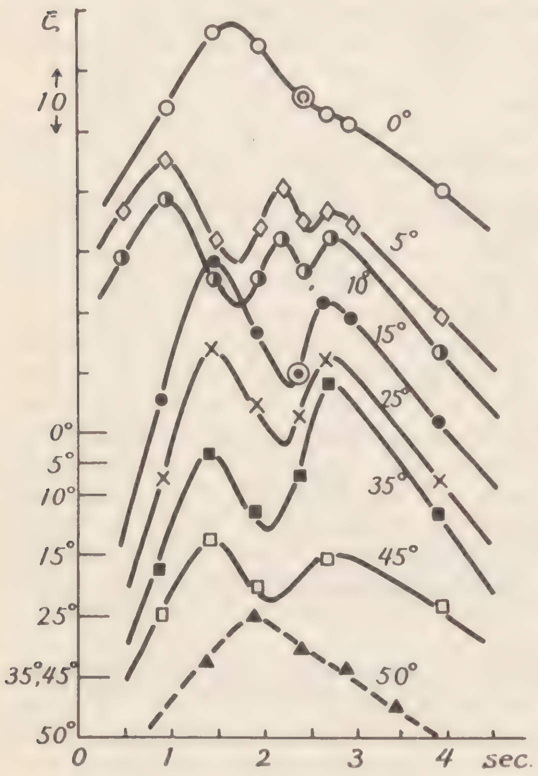

Figure 17. Effect of retinal position on the ζ-time curve of the normal eye. Motokawa (35).

First, it is seen in Figure 19 that for the normal subject the B process holds up well until stimulation is applied in the extreme periphery. The R and G processes meanwhile diminish in excitability. The broken line in the foveal section of Fig. 19 represents data taken with a time delay of 1.5 sec. Here the Y process curve shows two humps, one each at R and G. This was interpreted by Motokawa to mean that there is no independent Y process in fovea. Outside of the fovea, however, the Y process at 15° and 25° and 35° shows up to be stronger than the R and G. In the fovea, the R and G have maxima somewhat different from what appears parafoveally, and the R has a slight hump in the short wave lengths at about 440 mμ. Another point to note is that at 35° the center of the three processes is elevated over what it was at 25°. This Motokawa marked S (scotopic) to distinguish it from the G process. The broken curve (V) in the bottom section of Fig. 19 is a scotopic curve determined with a flicker photometer. Since both S and V are seen to cover the same spectral range with maxima at the same position, they were interpreted as a reflection of rod activity.

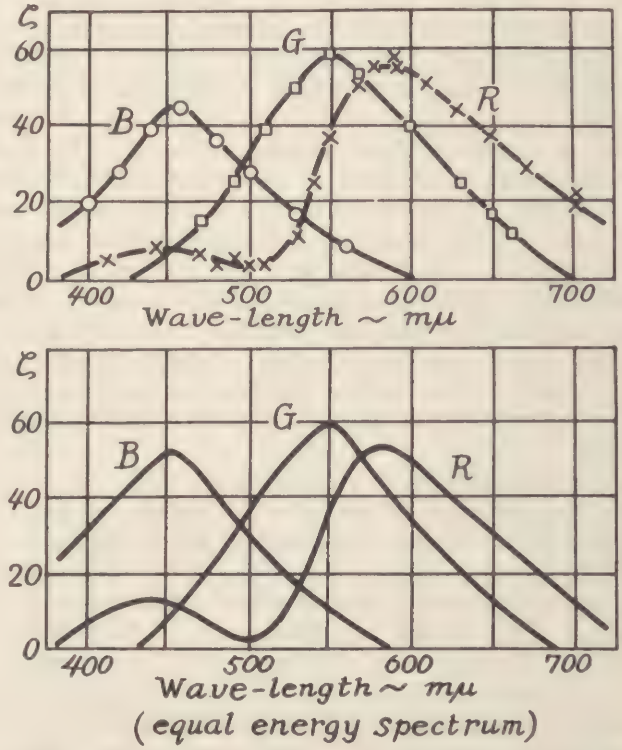

Figure 18. Physiological sensation curves: relation between excitability and wave-length when the value of ζ is measured at each wave length holding time τ constant at 1, 2 and 3 seconds for R, G and B, respectively. Motokawa (35).

The deuteranomalous data in Figure 20 need little comment. The Y process is shown as absent from the fovea but appears in the periphery. The weak G process diminishes rapidly and drops out at 25°. The S curve again turns up at the extreme periphery.

Dichromats. Data on dichromats were

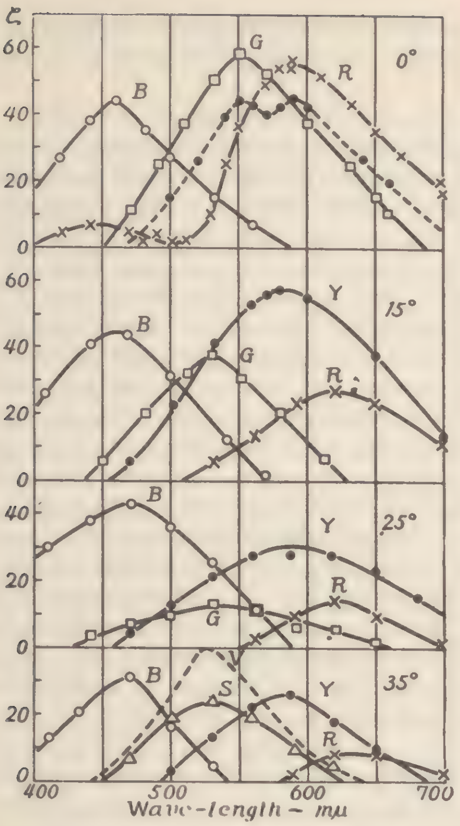

Figure 19. Effect of retinal position on the physiological sensation curves for the normal eye. Motokawa (36).

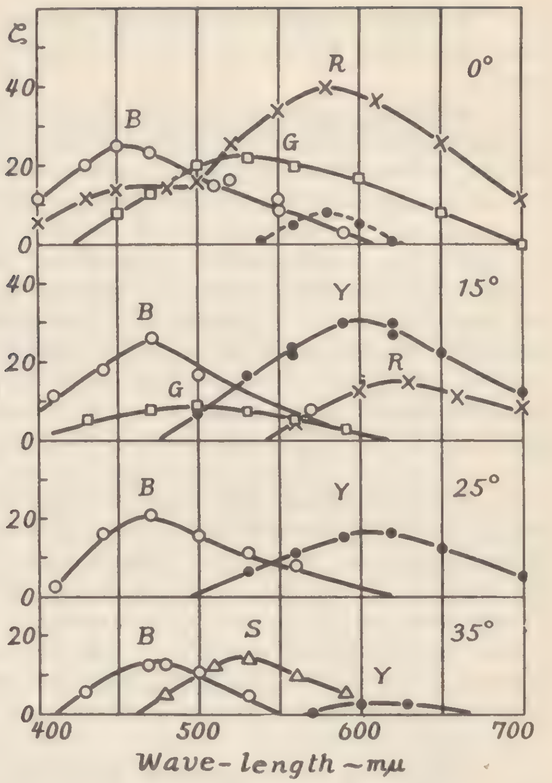

Figure 20. Effect of retinal position on the physiological sensation curves for the deuteranomalous eye. Motokawa (36).

presented in several papers (9, 36, 65). In general, alterations in the ζ-time and physiological sensation curves were as would now be expected. The ζ-time curves showed the protanope to have a depressed excitability at about 1 sec. and the deuteranope at about 2 sec. In the physiological sensation curves the protanope lacked the R process curve and the deuteranope the G curve. Data on the physiological sensation curves for dichromats were very clearly in agreement with prediction. In the ζ-time data as presented in papers by Motokawa (36) and Motokawa and Suzuki (65), there appears to be contradiction in the way the protanope behaves. More helpful are the data given by Ebe, Isobe and Motokawa (9) and shown in Fig. 21, where it is made quite evident that excitability in the protanope is shifted to the longer times corresponding to the shorter wave lengths.

Motokawa and Suzuki (65) reported that if, in the case of the deuteranomalous person, the intensity or size of the pre-illumination was reduced, the weak elevation in the ζ-time curves disappeared and the result could not be distinguished from that of a deuteranope. In this paper they also presented further data on the $\zeta - \lambda$ relationship for dichromats and anomalous trichromats.

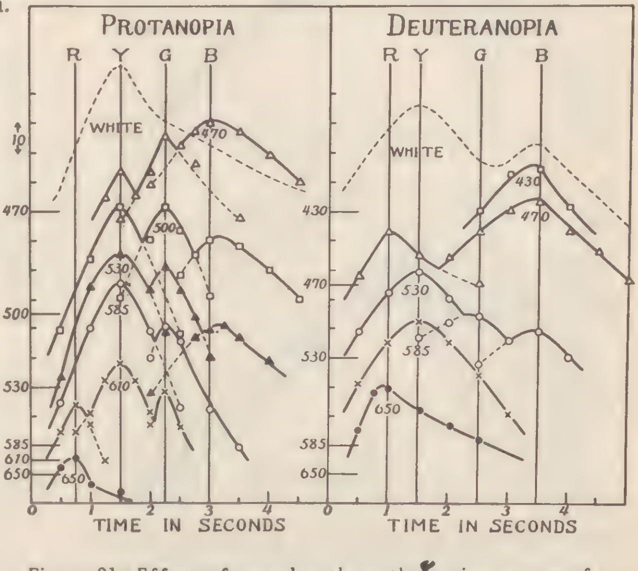

Figure 21. Effect of wave length on the ζ-time curves of protanopia and deuteranopia. Ebe, Isobe and Motokawa (9).

It is worth mentioning, in passing, that the electro-stimulus method is claimed to be more sensitive than conventional tests in detecting the presence of color deficiency (36).

Inhibitory action of color light. Motokawa opened up a new area for electro-visual investigation by the accidental discovery of an effect he called selective inhibition (47). During some experiments on summation (46) he happened to be working in a room that was not completely dark but was faintly illuminated by green light. The effect of this changed condition was to deform the ζ-time curve in this way: In the normal eye with white light the presence of the green illumination was to cause the curve to have two maxima instead of one and thus resemble data obtained from a deuteranope. Two hypotheses to explain the disappearance of part of the curve were suggested. First, that the effect was simply selective adaptation. This was rejected when it was found that the green light had to be present during the time course over which excitability was measured. It could not be removed with the termination of pre-illumination. The second hypothesis was that the green light had a selective inhibitory influence on the development of the G process.

An example of the data obtained at the fovea of the normal eye is shown in Fig. 22 where in the upper curve light of 550 mμ is seen to greatly reduce the G process and leave the R and B intact. The shaded area represents the inhibitory effect. In the lower curve light of 585 mμ eliminates the R and G processes and leaves the B. Motokawa's theory was that if it was assumed that white light aroused the R, G and B components in some definite proportions and that the inhibitory light withdrew some of the excitation process from particular components, the excitability curve would be the result of what was left. This process apparently operated on a complementary basis.

Figure 23 shows how an analysis by inhibitory lights applies to yellow pre-illumination of 589 mμ in which the maximum for ζ in the normal fovea occurs at about 1.5 sec. as shown in curve A. The effect of light of 550 and 530 mμ is to inhibit the G component of yellow light but not the R. Light at 430 mμ takes out some of the R, and B, and leaves the G intact. A mixture of 430 mμ and 680 mμ eliminates the R completely and leaves the

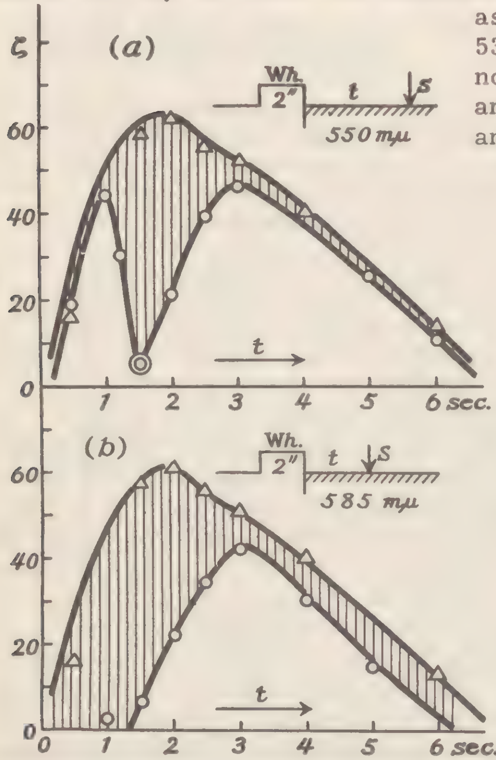

Figure 22, Alteration of the ζ-time curve of white light by inhibitory colored lights. The upper curves are the normal ζ-time relations for the white light. The lower curves are due to the action of 550 and 585 mμ. The shaded area is the amount of inhibition. Motokawa (47).

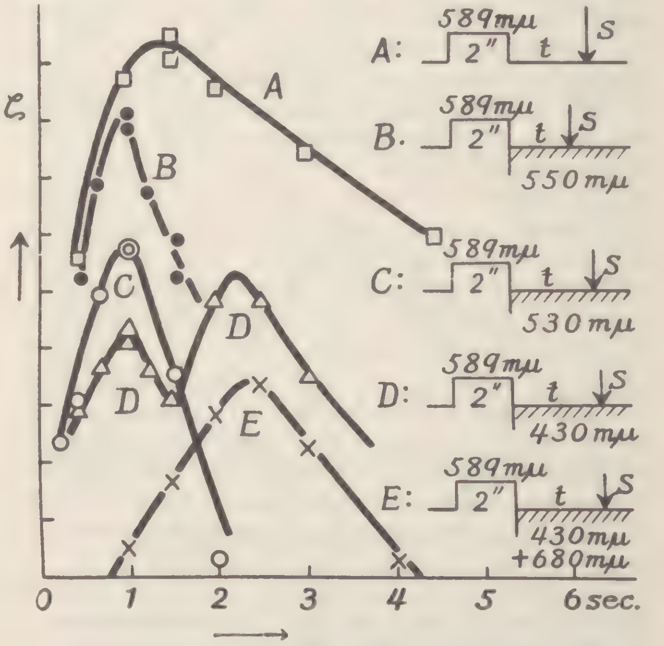

Figure 23. Analysis of light of 589 mμ by selective inhibition. Motokawa (47).

G. Motokawa felt that this demonstrated the dual nature of the effect of yellow light in the fovea.

For the parafovea, where he reported to have found a separate Y process (36) in both normal and deuteronomalous eyes, he concluded on the basis of a similar analysis using selective inhibition, that the Y process is unitary and not composed of R and G. However, it is not clear from the data presented in this paper that this is the case.

The next report on this matter was by Motokawa and Suzuki (67) and dealt with the problem of where, in time, to introduce the inhibitory light for greatest effectiveness. The first thing the authors did was to measure inhibitory effectiveness, as related to the R, G and B processes, by presenting a flash of inhibitory light at varying intervals before and after the electrical stimulus is given. The measure ζ was again used and inhibition was expressed as the difference in ζ -units between a normally determined excitation value and that obtained when the inhibitory light was used. An example will help here. If Motokawa wished to measure the inhibitory effect of light of any wave length on the R process, the ζ -value taken one second after stimulation with white light would first be found. This would be maximum for a normal eye. Then an identical measurement of ζ would be obtained with pre-illumination ceasing at a moment 0.5 sec., say, prior to the electrical stimulus, which was always deliverd at precisely the 1 sec. mark. The difference between these values of ζ is the inhibitory effectiveness. To study the inhibitory effect on G and B processes, the same thing would be done, except that 2 and 3 sec. would have to be used. The interval between the inhibitory flash and the electrical stimulus was called the I-S (inhibition-electric stimulus) interval. It was considered positive when the flash preceded the current and negative when it followed. Figure 24 shows the effectiveness of light of 650, 530 and 470 mμ on the R, G and B processes at the fovea of a normal eye. The upper curves are the result of presenting the inhibitory light immediately after pre-illumination and turning it off at fixed times before the electrical pulse. The lower curves are the effect of a 1/20 sec. flash. Both sets agree to the extent that the optimum I-S intervals turn out to be zero, 0.13 and 0.37 sec. for R, G and B, respectively.

Moving out on the periphery 15° from the fovea revealed a fourth I-S interval, measured from a base 1.5 sec. after pre-illumination. This is the locus of the ζ -time maximum of the Y process. This I-S interval was at 0.07 sec. and was noted to lie between the R and G intervals.

At the extreme periphery, 40° from the fovea, another optimum I-S interval appeared at 0.05 sec. Since this new interval could not be demonstrated to be affected by the wave length of the inhibitory light, it was suggested as being due to scotopic or rod action.

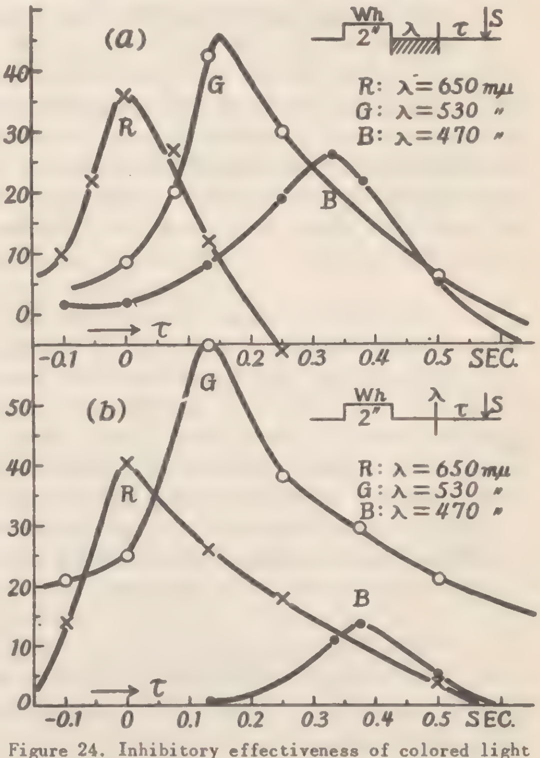

Figure 24. Inhibitory effectiveness of colored light on the R, G and B processes of the normal eye. See text. Abscissa: the interval between the inhibitory light pulse and the electrical stimulus. Motokawa and Suzuki (67).

Table I on the following page summarizes the characteristics of the basic retinal processes in the normal eye as shown by Motokawa's method and a 2° stimulus spot. The authors felt that the time relations in photopic vision stood together pretty well but that the scotopic process was a thing apart. Classical attempts to determine whether photopic or scotopic reactions are the faster were claimed to be irrelevant. The speeds of these reactions were

TABLE I

Characteristics of the Basic Retinal Processes of Normal Man as Revealed by Electrical Stimulation of the Eye

Motokawa and Suzuki (67)

Kind of retinal process		Maximum Excitation Time (sec.)	Optimum I-S interval (sec.)	Maximum spectral locus
	R	1.0	0.00	590 mμ in fovea 620 mμ in periphery
	Y	1.5	0.07	585 mμ
Photopic	G	2 (2-2.25)	0.15	550 mμ in fovea 530 mμ in periphery
	B	3 (2.75-3)	0.35	460 mμ
Scotopic	S	2.0 (4.5)[6]	0.05	520 mμ

shown to overlap, depending on what aspect of the photopic process was measured. Nevertheless, Motokawa and his associates proceeded to examine the nature of the scotopic process further in several recent papers.

Motokawa and Ebe (49) and Motokawa, Ebe, Arakawa and Oikawa (51) reported, first, that while the ζ-time curves at the fovea depended little upon the duration of pre-illumination, those at the periphery had their maxima shortened by increasing durations. But the maxima remained the same if measurements were dated back to the onset of pre-illumination. This finding was correlated with "on"-type elements associated with the rods. Second, the true maximum time for the photopic process was amended to 4.5 sec., or the slowest in the retina; cf. Table I. Third, when ζ was measured at 4.5 sec. for flashes of spectral light delivered to a retinal area 20^{o} from the fovea, the resulting ζ - λ curve coincided almost exactly with the scotopic visibility curve.

In another paper Motokawa and Suzuki (66) pursued the quantitative aspects of inhibitory lights further. The aspects they considered were intensity and wave length of inhibitory stimuli as they affected the amount of inhibitory effect. The experiments were done with the optimum I-S intervals for the R, Y, G and B processes as described above. The general results indicated, first, that inhibition increased with an increase in the intensity of the inhibitory light. This was true for all of the color processes. Second, inhibition was related to wave length more or less the way ζ is related to wave length. Therefore, the inhibition distribution curves closely resembled the physiological sensation curves shown in Fig. 18. Indeed, the maxima of these curves were claimed to correspond, within the limits of experimental error.

Microstimulation studies. Two studies have been carried out by Motokawa, et al., (50, 52) using the microstimulation technique of Hartridge (19) to obtain small areas of pre-illumination. The work on electrical excitability to this point had been done with test

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[6]The 2 sec. excitation time shown in the table is properly 4.5 sec., according to more recent measures (49,51). See below.

patches of 2^{o}. Now a pre-illumination area of 2' of arc was employed in, or near, the center of the fovea and at 20^{o} from it. It was found that in the fovea the R, Y, G and B processes existed as revealed by the ζ -time and ζ - λ curves. At the very center, however, no measurable Y response and only a weak B were observed. Near the center, or out to about 1^{o}, the R and G process responses predominated and beyond 2^{o} the Y and B processes took over. The maxima of the three physiological sensation curves obtained with the 2^{o} patch had been 585, 550 and 460 mμ for R, G and B, respectively. For the 2' patch these become four in number at about 610, 575, 520 and 460 mμ for R, Y, G and B, respectively. The three-components maxima were observed to correspond well both with Granit's maxima of 600, 530 and 460 mμ for the spectral sensitivity of modulators in the cat's eye, and the general maxima in the sensation curves found by numerous investigators for color matching.

Work at 20^{o} from the fovea confirmed the strong Y and B process excitability and the weak R and G. The conclusion reached from these studies was that they confirmed and extended Hartridge's observations on the nature of the foveal receptor mechanism.

Evidence from retinae of frogs. Since this review is intended to treat the results of electrical analysis of the human eye, no attempt will be made to do other than mention the work Motokawa and his associates have done on frogs and toads. It is important to note, however, that seven papers have been submitted to show that much the same relationships found in human eyes can also be demonstrated in frogs (35, 55, 56, 57, 61, 63, 79). The method was essentially the same as has been described, the indicator of excitation being action potentials taken from the optic nerve. Except that the action of the amphibian eye was sluggish, the ζ-time curves showed about the same characteristics as the human curves. The white, R, G and B elevations of the ζ -time curves could be clearly seen, as well as the dependence of these curves on intensity. The phenomena of selective inhibition were demonstrated in a manner analogous to that found in the human eye. Indeed, even color contrast, to be described for human subjects in the next section, was observable in the responses of the frog's retina.

The existence of these and other phenomena in the non-human eye, was emphasized by Motokawa as indicating anew the basic physiological nature of his electro-stimulation method. It is especially to be noted that the work by Motokawa, Iwama and Tukahara (63) and Tukahara (79) on modulators and dominators was shown to give results that correspond well with Granit's studies.

Summation, contrast and optical illusions

The generality of using an electrically aroused phosphene in investigating the effect of photic excitation processes was shown next to extend to such phenomena as summation, simultaneous and successive induction, and numerous optical illusions.

Spatial summation. The first paper on summation was by Motokawa (41) who studied the effect of using, singly and together the arrangements of test patches shown in Fig. 25. He used configuration A (Fig. 25) to determine the effect of the angular separation of five circular spots of light on values of ζ . Comparison was made with ζ for a single patch. The intensity was 1000 lux and the exposure of the test patterns was 0. 13 sec. Table II shows the summation effect due to the use of five spots over one spot. Summation is seen to disappear when the separation in the multiple spot figure is about five degrees. That the amount of summation depends upon intensity was shown by separate measurements using 5200, 280 and 180 lux. These intensities gave limiting values of separation of 13.6^{o}, 7^{o} and 3.5^{o}, respectively. It was pointed out that Granit (14) found summation in a four spot experiment using flicker with a separation of 2^{o} and an intensity of 100 lux.

The effect of retinal position was measured with arrangement B in Fig. 25. The

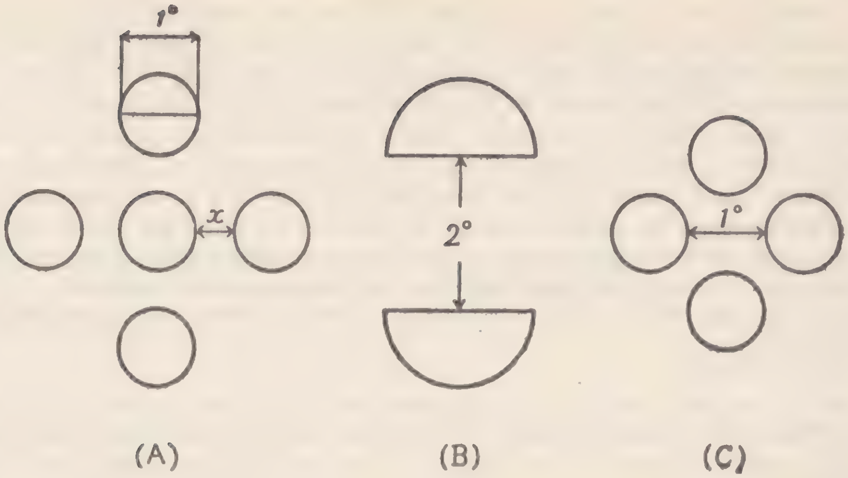

Figure 25. Stimuli used to study spatial summation. Motokawa (41).

TABLE II

Summation effects at varying degrees of separation between stimuli for Fig. 25(A) in values of ζ. Motokawa (41).

X in degrees	Single spot	Five spots	Summation effect (difference)
0	54.5	77.0	22.5
1	"	75.5	21.0
2	"	68.0	13.5
3	"	64.0	9.5
4	"	58.5	4.0
6	"	54.5	0.0

TABLE III

Summation in values of ζ at various regions of the retina. Stimuli as in Fig. 25 (B). Motokawa (41).

Degrees from center	Single patch	Double patch	Summation effect
0	63.5	69.0	5.5
20	50.0	55.5	5.5
40	42.0	48.0	6.0

results appear in Table III. The intensity was 1000 lux. Here the ζ-value is seen to decrease but the summation remains the same, indicating a greater percentage increase at the periphery than at the center of the field. This effect was verified for the 1000 lux intensity in another experiment, in which arrangement C was used. When the intensity was reduced to 8 lux, however, the summation effect could no longer be seen beyond 10° distant from the fovea.

ζ and the area stimulated. This relationship was studied at 1000 lux for the fovea and at 20° and 40° in the periphery. The exposure time was 0.13 sec. The results are in Fig. 26. These curves are of the same general shape as the ζ-log I curves discussed in the first section (59).

Summation of colored light. Motokawa found scant evidence of this in an experiment in which he had a split-field, 2° patch that could be illuminated with either one or two colors. Filters were used to obtain red (620-740 mμ), green (490-550 mμ) and blue (410-490 mμ) illumination. Stimulation was confined to the rod-free area. The ζ-value for homogeneous illumination of the patch was increased markedly by doubling the area. ζ rose from 42 to 75 for red, 43 to 71 for green, and 45 to 69 for blue. The solid lines of Fig. 27 show the extent of interaction with pairs of lights. The dotted lines indicate the use of the colors separately. Practically no interaction exists when the colors are spectrally separated as in the red and blue. Some occurs when the pairs lie closer together. Motokawa explained this in terms of the three-component theory on the basis that individual lights will stimulate more than one color process when they are near each other in wave length but not when they are widely separated.

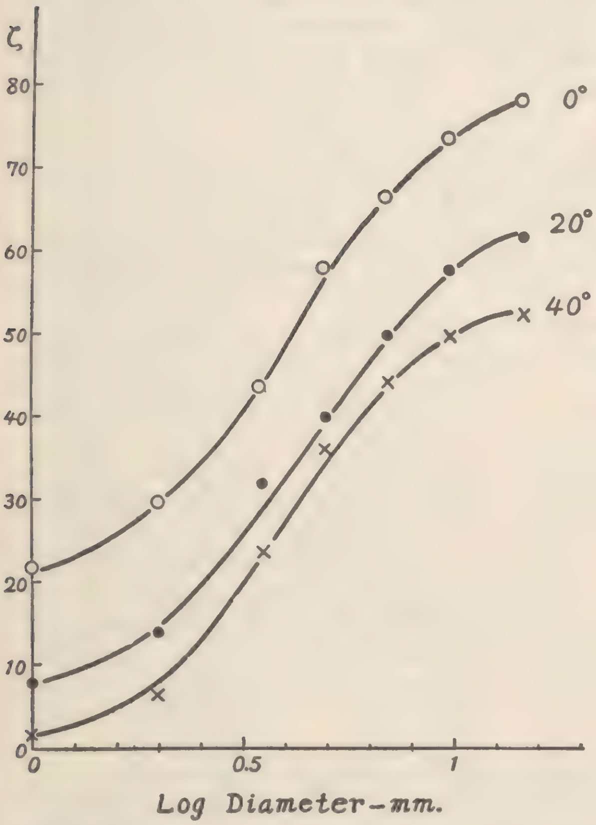

Figure 26. Dependence of excitability on area at different retinal positions. Motokawa (41).

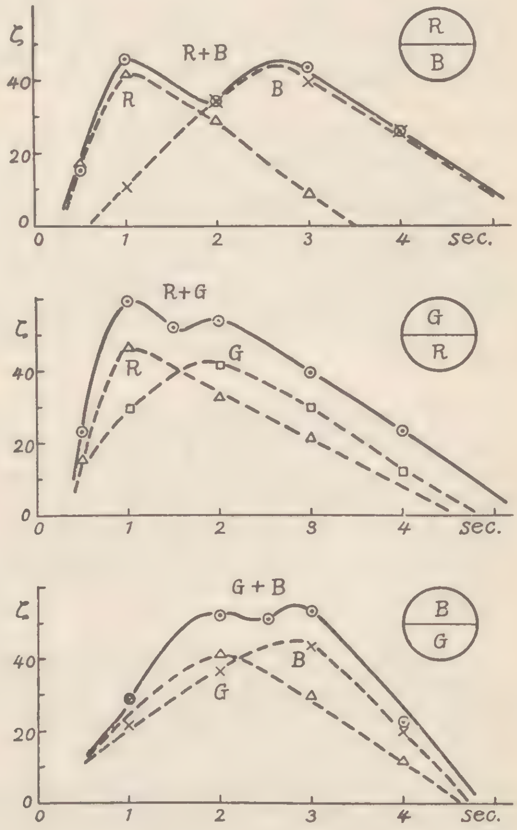

Figure 27. Interaction between colored lights as seen in the ζ-time curves. Motokawa (41).

In another experiment Motokawa (46) looked into the matter of summation by direct color mixing where the arrangement allowed no separation between the areas where light fell on the retina. He found that a mixture of yellow (580 mμ) and blue (450 mμ) produced no significantly larger values of ζ than the two lights taken separately. This was also the case when 650 and 470 mμ were mixed. He concluded that the law of additivity normally found for color mixing does not hold for the physiological measure of excitation as determined by his method.

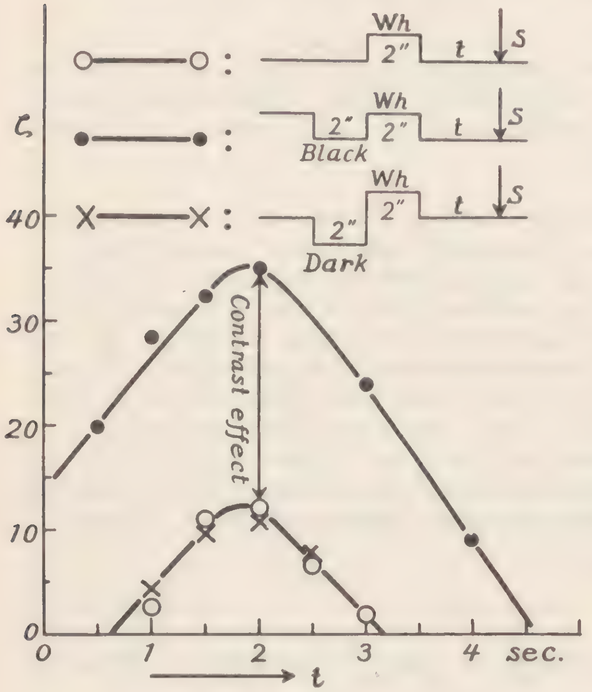

Figure 28. Effect of successive brightness contrast on the ζ-time curves. Motokawa (37).

The next problem that Motokawa treated was that of color and brightness contrast (37). The method again was a simple extension of his general procedure. What he did in this case was to measure ζ by introducing the electrical test stimulus after a contrast situation had been set up. The insets in Figs. 28 and 29 show how the stimuli were ordered for brightness contrast.

Brightness contrast. To study the effect of successive brightness contrast on electrical excitability, a 2° test spot was seen against the background of a screen held at 0.05 lux. The test spot was either black (no light) or white (84 lux). These were presented successively as indicated in Fig. 28, where the results are also shown. ζ is raised, when the black stimulus precedes the white (upper curve), over what it is when white alone is used (lower curve - open circles). To rule out the effect of adaptation, the screen was darkened for 2 sec. before the white patch was given. This, as shown in the crosses of the lower curve, had no effect. The amount of contrast was further shown to depend, somewhat, on the duration of the black stimulus and, more particularly, on the intensity of the adapting field. The contrast effect increased as the intensity of the adapting screen was raised, since raising the field level increased the "blackness" of the dark spot.

Simultaneous contrast was also investigated by placing a bright patch within a dark, concentric ring. The effect of this was to raise ζ from 13 to 34.5. The difference in excitability in this instance was considered due to contrast.

Color contrast. Successive color contrast is shown in Fig. 29, where it is seen that if white light is preceded by colored light, the ζ maxima occur at times corresponding to the complement of the colored light used. White light, however, has no effect on the excitability curve of white light. This is seen in Fig. 29 (a). Further experiments showed the contrast effect to be

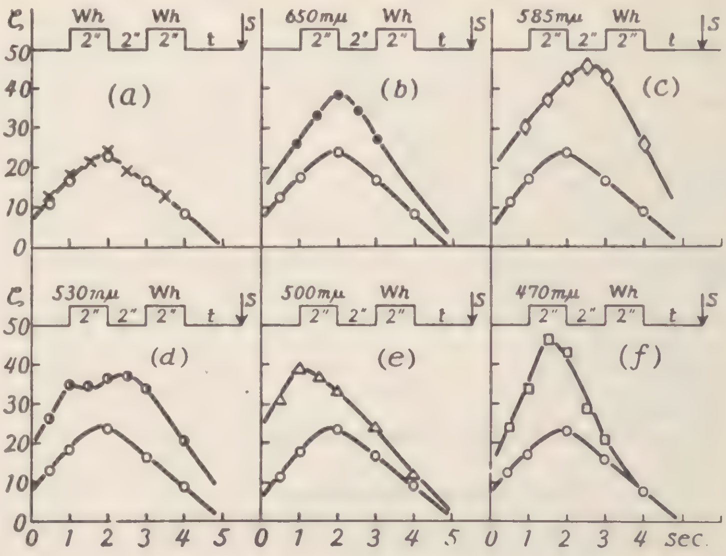

Figure 29. Effect of successive color contrast. Motokawa (37).

dependent on the intensity of the inducing light, but not on that of the white test light.

Motokawa's supposition, as set forth in this paper (37), was that an optical image formed on the retina produced in the surrounding area a field of induction that could be mapped out by his electro-stimulus method. Now he proceeded to demonstrate this in two papers on retinal induction (45, 48).

Optical illusions. In the first report Motokawa measured the induced field surrounding geometrical figures (squares, triangles and circles) and certain specialized configurations such as the Hering squares, Wertheimer-Benary contrast figures, the Müller-Lyer illusion, and the Landolt ring (45). The procedure was to present an intense, yellow (sodium lamp) stimulus to the retina in the shape of the inducing figure. This exposure was 2 sec. Then, after a delay of 3 sec., a small white test light was presented in different parts of the retina surrounding the inducing yellow exposure. This second exposure was also for 2 sec. Finally, a 100 msec. electrical pulse was applied to the eye after a second delay of 1.5 sec. (ζ maximum for Y) for the purpose of finding the threshold phosphene. Contrast was defined as before; i.e., by the difference between the ζ-value determined for white light and the ζ-value determined after the above procedure.

The startling finding was that a gradient of field, as defined by this electrical measure of a contrast effect, existed around a given stimulus figure. The excitability field was strongest at the margins of the figure and fell off to zero with distance from the boundary. The rates at which the field strength declined depended upon where, with respect to the boundaries of the figure, the field was measured. Measures of field strength were used by Motokawa for constructing geometric representations of the gradients surrounding different figures. For example, the shape of the field surrounding a circle was circular, but the field surrounding a square was in the form of a cross, with the field falling off most sharply at the corners.

The same general procedure was then used to explore the retinal surrounds of the illusions mentioned above and it was shown that the fields of retinal induction were distinctively patterned by the figure involved. The suggestion was made that the experience of illusion may perhaps be accounted for by deformations in the fields of retinal induction surrounding a figure. These fields may be due either to the figure itself or to some other configurations in the vicinity. In either case, physiological processes serving the retinal image are warped or modified in a manner characteristic of the illusion.

Propagation of induction effects. This very fascinating work was studied in further detail in the second paper (48) on color contrast effects. Motokawa at this time introduced some new terminology. By direct induction he means the residual effect left in the same area of the retina by stimulation with colored light. It may be measured by his electrical method in the manner already described; i.e., by comparing ζ for white light alone, with ζ for white light that has been preceded by colored light. So if yellow light is used, excitability will increase in the region of the ζ-time curve where the B process is, or, in this case, at 3 sec. Now if the yellow light is followed by the proper amount of exposure to blue light before the test with white light is made, the enhancement at 3 sec. disappears and the ζ-time curve is identical to the simple white light curve. This is called neutralization. If the intensity of the neutralizing blue light is too high, over-neutralization occurs.

Motokawa then studied the effect of the intensity of the neutralizing light in direct induction and the temporal position of the neutralizing light with respect to the inducing light. With regard to the latter, he found that the contrast effect of an inducing light persists for 15 sec. or more and that the effectiveness of a neutralizing light increased the later it followed the inducing light.

By indirect induction is meant the residual process that exists in an area adjacent to the area stimulated. If the ζ -time curve is obtained using a white test patch in an area next to where yellow light has acted, the crest will be at 1.5 sec., not at 3 sec., as in the direct induction case where the same retinal area is involved. This effect may be neutralized by a light of the same color as the inducing one.

The previous work (45) had shown that retinal field gradients were rather extensive. Indeed, they were astonishingly large, sometimes reaching out from the area stimulated as much as 4-6°. By setting up an "inducer-detector" arrangement in terms of stimulus lights, Motokawa next showed that the effects of indirect induction were propagated over distances of 46 degrees of arc in the retina. This propagation effect would not pass thru the blind-spot nor across a barrier formed by the image of a white light stimulus.

The whole area of vision that Motokawa has touched upon in the studies reported in this section has been one in which little real progress has been made, in spite of great interest, especially on the part of psychologists. The discovery that measurable alterations in the electrophysiology of the retina occur during contrast and illusion processes is most welcome. This approach should afford an engaging challenge to many workers in the field of vision.

The strength-frequency relationship

It has long been known from work on tissues other than the eye that optimum frequencies of excitation exist at which thresholds to intermittent electrical stimulation are lowest (27). U-shaped curves result when threshold current (I) is plotted against log frequency (n) (7). The I-log n curves are symmetrical about the optimum frequency and their theoretical importance has been discussed in detail by Hill (21), Coppée (7), Katz (24) and Schaefer (70). Rohracher (69) showed in 1935 that the strength-frequency curve for just noticeable flicker phosphenes passed through a minimum at about 20 c./sec. His data were obtained with sine waves for the light-adapted eye. Schwarz (71, 72, 73, 74, 75) verified and extended Rohracher's observation that only one frequency of maximum stimulus effectiveness existed for the light-adapted condition; Fig. 30. Motokawa and Iwama (60) and Abe (1), however, reported three and five minima, respectively, for thresholds during light adaptation, although in another place Motokawa reported data on two minima, while mentioning three and four (38). Abe, further, found that the minima during adaptation were not the same as during the light condition. Some of their results are shown in Fig. 31. It is interesting to note that, for Abe, the 20 c./sec. minimum disappears altogether during dark adaptation. Motokawa considered this to be essentially a resonance phenomenon, with the most conspicuous natural frequency of the eye at about 18 c./sec. for the light-adapted condition. He offered in support of this evidence that the period of oscillation into which the eye was thrown by a sensitizing electrical shock was 54.85 msec. (44). This worked out to be about 18.2 c./sec. and corresponded well to the strength-frequency data.

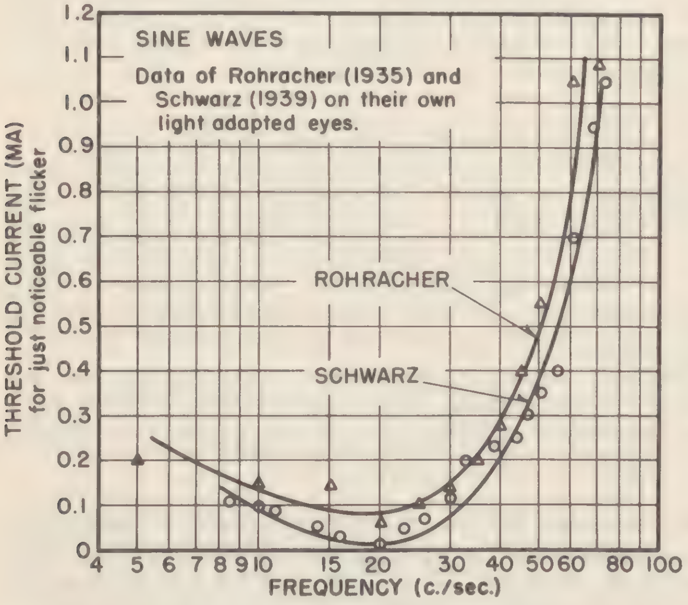

Figure 30. Strength-frequency relationship for the light-adapted eye. After Rohracher (69) and Schwarz (72).

This is the first, and to date the

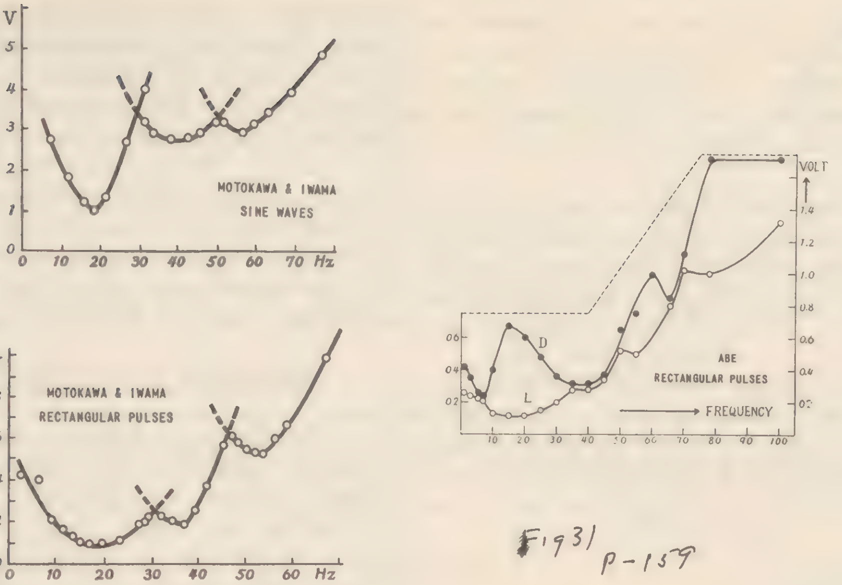

Fig 31 p-159

Figure 31. Strength-frequency relationship found for the light-adapted eye by Motokawa and Iwama (60) and for the light-adapted (L) and dark-adapted (D) eyes by Abe (1).

only, opportunity available to compare any of the findings of the Motokawa school with those of other investigators who have recently looked into the visual electro-stimulation problem. It has already been mentioned that Rohracher and Schwarz found only one minimum in the strength-frequency curve. Gebhard (11, 12), using a variety of different wave forms, also found but one minimum clearly discernable. This was at 20 c./sec. for all conditions studied, although the values of the thresholds were shown to depend on certain other factors. Figure 32. These were: the position in the visual field where the phosphenes were judged, and the adaptation level. The periphery of the field was found to be more excitable than the center and the retina, when adapted to 0.1 mL., to be more sensitive than when adapted to 10 mL. Wave form and polarity were unimportant.

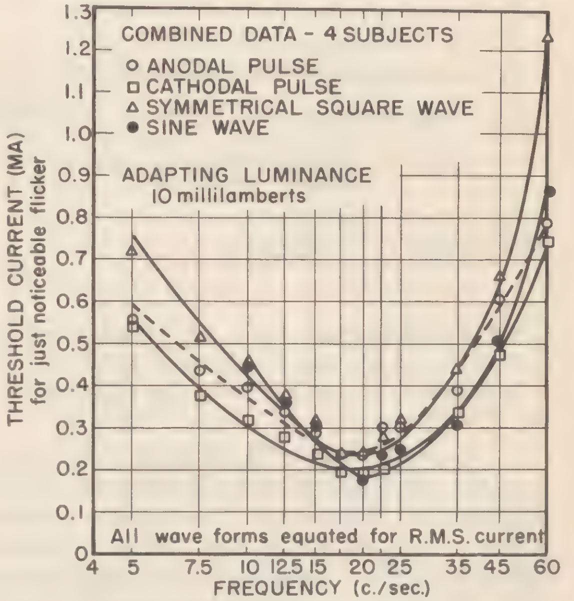

Figure 32. Strength-frequency relationship for the light-adapted eye found by Gebhard (12).

As for the dark-adapted eye, this was studied at some length by Schwarz (75). Abe's findings on this point are completely at variance with Schwarz' data. Nevertheless, Abe's supposition that the absence of the 20 c./sec. minimum under dark adaptation was due to the low electrical excitability of the rods was pursued further by Tukahara and Abe (80). These authors obtained ζ -time curves on dark-adapted eyes, for pre-illumination with intermittent white light. They concluded from an analysis of their data that the natural resonant frequency of the rods was 20 c./sec. Figure 33 shows the excitability of the rods measured under two different conditions. The upper curves are for pre-illumination by white light 60^{o} from the fovea, with ζ determined at 1, 2 and 3 sec. The lower curves are for red (crosses) and blue (circles) lights applied parafoveally at intensities below the cone threshold. These data indicate an increase in excitability at 20 c./sec. that was taken to

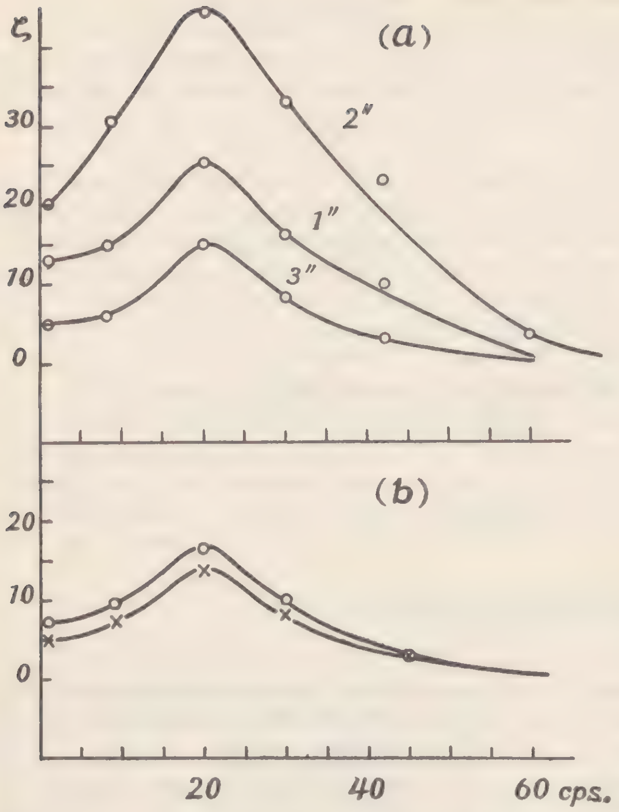

Figure 33. Excitability of the rods. See text. Tukahara and Abe (80).

represent rod activity due to light. If, however, light was removed, the rod sensitivity at 20 c./sec. disappeared. This was held to account for the absence of the 20 c./sec. minimum under dark conditions. Unfortunately, nothing can be concluded from all this. Either there is only one minimum in the strength-frequency curve or there are more. There are objections to be raised against all the investigations. It looks as though this problem requires restudy.

Measurement of General Fatigue

People have been trying for years to tease an indicator of fatigue out of photic flicker effects. (6, 29, 76). The success of this effort has been small. Notwithstanding the poor record of using light, Motokawa and Suzuki (58) introduced in 1948 a method of measuring fatigue that made use of the electrically aroused phosphenes. The procedure was first to impress 20 c./sec. pulses across the head in the manner by now familiar. Under a normal, rested condition the thresholds S_1 and S_2 were obtained for the appearance and disappearance of flicker, respectively, by increasing and decreasing the stimulus voltage at a uniform rate. S_1 was found always to be higher, so the difference ΔS_o was gotten by subtracting S_2 from S_1. Therefore,

$$\Delta S_o = S_1 - S_2.$$

This process was then repeated after fatigue to obtain the difference, ΔS. The comparison between ΔS_o and ΔS was made by finding their difference. $\Delta S - \Delta S_o$, therefore, is a measure of fatigue that is reported to be sensitive enough to be useful.

Correlation with oxygen deficiency. In a paper that appears to have been written earlier than the above, Motokawa and Iwama (58) reported work on electrical excitability and oxygen deficiency. Here also were used appearance and disappearance thresholds for flicker and the difference between them. Measurements were taken under moderate light adaptation in a low pressure chamber over a range of pressures equivalent to over 20,000 feet of altitude. The main result was that while the mean of appearance and disappearance thresholds stayed about the same, the former rose somewhat while under low oxygen pressure, whereas the latter fell. The difference between them, then, turned out to be a sensitive indication of oxygen deficiency and can be seen to be like the ΔS term referred to above. The authors also measured the sensitivity of the eye to light during decreased oxygen pressure and concluded that their new found measure of electrical excitability was the more suitable.

Effect of work. Suzuki (78) next carried the method over into the field of exercise and compared oxygen consumption with thresholds of electrical flicker. The electrical data before and after work was expressed as $\Delta S - \Delta S_o$. The oxygen consumption was measured by conventional methods and was expressed as the difference

$$0 - 0_o$$

where 0_o is the quantity of oxygen consumed per minute at rest and 0 is that consumed during work or in the course of recovery from work. In a series of experiments on the bicycle ergometer, running and stair climbing, the data from the two methods ran parallel to each other with remarkably small discrepancies. Suzuki concluded that the two methods were measuring the same thing and that $\Delta S - \Delta S_o$ was perhaps the more sensitive.

A point of difference that should be mentioned is that whereas Motokawa and Iwama (58) found the mean values of appearance and disappearance to stay the same for reduced oxygen pressure, Suzuki's results showed that S_1 and S_2 tended to change in the same direction, while at the same time their differences were changing. The difference, nevertheless, continued to be the critical feature of the measure.

Suzuki (77) also studied the course of $\Delta S - \Delta S_o$ during the daily activities of workers. Three classes of workers, chosen on the basis of the estimated amount of fatigue involved in performing their jobs, gave the results shown in Table IV. The data are not extensive, but there is little overlap. These data were offered as further evidence that Motokawa's method was measuring something useful and real.

TABLE IV

Maximum Degree of Fatigue in Industrial Workers as Measured by Motokawa's Method. After Suzuki (77).

Class of Work	Type of job	Maximum fatigue ($\Delta S - \Delta S_o$ range in mV)
Light (N-4)	Doctor, nurse, clerk, designer.	196-216
Medium (N=11)	Locomotive engineer, telephone girl, telegraph operator, etc.	212-380
Heavy (N=5)	Stoker, coolie	432-635

Research on the method. It had been mentioned by Motokawa and Iwama (58) that the rate at which the appearance and disappearance thresholds were approached seemed to be important in establishing the value of the thresholds. The matter of time was not well controlled in their experiment. The rate was controlled manually and the experimenter stopped varying the current at a signal from the subject. The experimenter's reaction time, as well as the subject's, undoubtedly caused a certain amount of overshooting. Mita, Abe and Byonshik (32) carefully controlled such factors in a study in which they investigated the dependence of ΔS on the intensity of ambient illumination, the frequency of the flicker employed and the rate of altering the stimulus current. They used a motor drive to control the rising and falling stimuli and a device that, at the subjects' signal, recorded where the stimulus value was at threshold. This eliminated the experimenter's errors, but, of course, not the subject's reaction time.

The results indicated that the measure ΔS could be analyzed into a factor S, which is the mean threshold, $(S_1 + S_2/2)$, and the reaction time T for the minimum stimulus. They proposed then, the equation

$$\Delta S = KS + 2TV,$$

where K is a constant and V is the rate of altering the stimulus current.

There are several psychophysical aspects of the data presented that require more study. For example, the frequency of the current pulses must be kept constant since thresholds measured at values above and below 20 c./sec. were observed to give somewhat larger measures of Δ S. This would appear to mean that the presence or absence of flicker can be more sharply discriminated at 20 c./sec. than any other frequency. Is there a significance in this for the strength-frequency relation? Another question is why should threshold be proportional to the rate at which the current is raised or lowered only when adaptation is held constant? These are but a few of the interesting problems raised by this analysis. The only safe conclusion for the use of Motokawa's test of fatigue, at any rate, is that Δ S should be measured under carefully controlled conditions. The authors of this paper suggested what these should be.

CONCLUSION

There can be little doubt that the reported work of Motokawa is exciting stuff. It represents a fresh and unique approach to vision that appears to promise great things. Unfortunately, this cannot be said without reservation. The work has come upon the scientific world so recently and in such volume that there has been little opportunity for visual workers to digest it, to say nothing of confirming it. Evaluation of Motokawa's findings cannot be made in any serious sense until a considerable amount of his experimentation has been redone, verified or modified, as the case may be. For the present, one can only say that the work looks good. Indeed, it almost looks too good, in that the data of electro-analysis and that of more conventional experimentation fit together, in many respects, so beautifully.

It is possible, of course, to point out some obvious shortcomings. These were touched upon briefly in the Introduction. The first has to do with the method of measuring the electrical thresholds. The reading of voltage is not the method of choice in this kind of work, although if proper precautions are taken voltage measurements may be reasonably satisfactory. For example, a frequent re-determination of E_o is certainly needed to eliminate the consequence of voltage changes due to variations in resistance. Motokawa probably does this, although he does not make it clear that he does.

The second difficulty concerns the amount of data Motokawa has used in presenting his material. Complete tables of the measures obtained are never given. Consequently no independent estimate of such matters as the variability of measures and the significance of differences is possible. Indeed, no statements are made about how many measures were used to determine any given point on the numerous curves published. It can only be observed that the points plotted from the data generally can be fitted very well by smooth curves. Data are always presented as typical examples of the measures obtained. The extent to which atypical data was collected cannot be judged. The number of subjects measured is rarely given. It appears that where multiple authorship occurs, the writers used themselves as subjects. Whatever the case, the impression is left that few subjects are used at any time. The reviewer also has the impression that only certain data of certain subjects are actually presented. It is realized that graphic presentation of all the data is usually space consuming, but the use of tables is not. There is no question but that a more complete reporting of the data would do much to satisfy critics in American laboratories.

The total work, nevertheless, remains very impressive, and these few criticisms are in no way intended to detract from it. This review cannot be a substitute for reading the papers. It is hoped that it will merely serve two purposes. First, to arouse some interest in the work, and second, to inspire a few workers who have available the facilities, to verify the investigations of the Tohoku laboratory. Such study should not be difficult, since the technique is clearly reported and appears not to be particularly involved. If Motokawa's work stands, it will unquestionably be one of the most important contributions to the physiology of vision in many years.

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Discussion:

Dr. Wald expressed sincere thanks to Dr. Gebhard for his useful review of the electro-stimulation research. Dr. Wald expressed his impression that the electro-stimulation results look extremely good; it is possible that the results are not as good as they seem to be at first glance. It is certainly clear that this research needs to be evaluated and may prove to be a very useful adjunct to other methods for studying the visual system.

Dr. Hartline also expressed his appreciation to Dr. Gebhard for the useful review. Dr. Hartline expressed his opinion also that the electro-stimulation research should somehow be correlated with other means of studying visual processes.

HOW LONG DOES IT TAKE THE HUMAN EYE TO DARK ADAPT?

George Wald and Robert C. C. St. George*

It is usually stated that the dark adaptation of human cones is complete within about 5 minutes, that of the human rods within 30 minutes to an hour. It is quite true that the major portions of dark adaptation are completed within these times; after such periods of dark adaptation have been completed, repeated measurements of the threshold made over periods of 10 or 15 minutes seem to be fluctuating about some mean constant value. Nevertheless measurements continued in the dark over much longer periods show that the threshold is still falling slowly. Achmatov (Arch. ges. Physiol., 215, 10, 1926) measured the visual threshold for 25 hours in the dark. He showed that throughout this interval the threshold gradually decreases. The total fall of threshold between the first half hour of dark adaptation and the twenty fifth was no more than 4:1.

We have recently confirmed this slow ending of the dark adaptation function. Both eyes were dark adapted for several hours. Then one eye was kept dark, while the other was light adapted very highly by exposure to approximately 10,000 millilamberts for 10 minutes. Thresholds were then measured alternately in both eyes in the dark. The light adapted eye yielded the conventional dark adaptation curve; but even after four hours its threshold (rods) remained measurably higher than that of the other eye which had been kept dark throughout.

Similar experiments in which the thresholds of red lights were measured so as to isolate the dark adaptation of peripheral cones, have shown that after highly light adapting one eye, its threshold is still about 0.15 log unit higher after 35 minutes than that of the other eye, which had remained dark adapted.

Dark adaptation therefore is completed much more slowly than is generally supposed. Its final stages may persist for hours after the completion of light adaptation.

SUMMARY OF THE REPORT

OF THE

EXECUTIVE COUNCIL

The chairman reported that the Executive Council met during the evening of Thursday, November 15. The Executive Council considered the report of the Executive Secretariat. Five activities of the Vision Committee were completed during the period since the last meeting of the Executive Council in April, 1951. These include the following:

a. The working group on night vision training

b. The working group on sunglasses

c. The working group on "Manual of Instructions for Clinical Testing of Visual Acuity"

d. The working group on color coding

e. The working group on cockpit and instrument lighting.

The Executive Council considered the status of continuing activities of the Vision Com-Committee. These may be listed as follows:

a. The working group on visibility at high altitudes

b. The working group on reflection optics

c. The working group on taxiway lighting and designation markings

d. The working group on optical gunsights

e. The working group on night vision testing

f. The working group on illumination and dark adaptation

g. Consultation services to the Naval School of Aviation Medicine, Pensacola, Florida, in regard to the effect of ultraviolet radiation upon dark adaptation.

h. Problem study of air defense radar

i. Problem study of color filter standardization

j. Problem study of searchlight specifications

k. Problem study of camouflage detection

l. Problem study of instructions for use by meteorologists in estimating visibility.

The Chairman reported that Drs. E. O. Hulburt and S. Q. Duntley have been elected to the Executive Council for terms running to July 1, 1953.

The Chairman reported that Dr. Donald G. Marquis has resigned as Executive Secretary and that Dr. H. Richard Blackwell has been appointed in his place.

The Chairman announced that the next meeting of the Vision Committee is scheduled for April 4-5 in Washington, D. C.

COMMENTS ON THE DESIGN OF ILLUSTRATIVE LANTERN SLIDES

Col. Victor A. Byrnes, USAF

The following general principles apply to slides to be shown at medical meetings. This is only a resume. For further information on the subject, reference is made to standard statistical texts.

1. Data should, whenever possible, be presented in graphic form. Tables of figures should be utilized only in rare instances. After all, Arabic numerals are only abstract symbols representing quantities. They require an additional mental process to give the observer an accurate impression of relationships between quantities. Graphic presentation of the data is much more effective. For this purpose bar diagrams, histograms, pie diagrams, location diagrams, line graphs, distribution diagrams, scatter diagrams, range diagrams and map diagrams are useful devices. Select the one which gives the best presentation of the relationship you desire to point out.

2. It is better to present only one comparison or one factor on a single slide. If several factors are to be compared, use several slides. If summarization is then desired, the salient points can be compared on a final slide.

3. Draw illustrations carefully so as not to distort their relationships. Be sure, for example, to start the scale on bar diagrams at zero or the diagram will give a false picture of the data.

4. Slides should not be prepared on a typewriter. Typewritten letters, when magnified by projection, appear fuzzy and indistinct on the screen. Slides should be prepared by making a large drawing and photographing it.

5. Achieve the maximum contrast. Wide, well outlined, black lines on a white background give more contrast and make the diagram easy to see and the relationship between components easy to comprehend. A well-prepared slide should be legible in a partially lighted room so those who desire to do so may see the speaker and take notes during a presentation.

6. Good contrast between background and letters is required. For this reason color cannot be used for the background of a slide unless the color is very light or the letters used are white. After all, color on the screen is produced by filtering other colored light out of the projection lamp spectrum. If the color is dark, the contrast with black letters is impaired and again it will be impossible to use the slide in a partially lighted room. Color can be used very effectively, however, in portions of the slide other than the background. It can be used to catch the eye, add interest and indicate relationships between related items. It may also be used to separate captions from data. Colored slides are readily obtained by photographing a colored chart on ektachrome, kodachrome or ansco color film and placing the transparency between standard glass plates.

7. Labelling should be as simple and nonconfusing as possible. Legend in bars or lines should unmistakably belong to the portion to which they apply. The scale must indicate the units in which the chart is drawn.

8. Only 3-1/4 by 4 inch slides should be used. The small 2 by 2 inch slides can only be shown in completely darkened rooms to small groups. The magnification required to give an image of adequate size in large rooms is excessive and results in indistinct outlines.

9. All letters and figures must have clear outlines and be of such size, width of line, and spacing that they can be seen easily by individuals with normal vision in the back row of the room in which they are to be shown. This requires that they be just readable by a man with 20/40 vision. If the letter height is about one-thirtieth of the height of the chart when photographed, the letter size on the slide will be adequate. No letters which measure less than 2 mm. in size on the actual 3-1/4 by 4 inch slide should be used. Letters smaller than this will not be visible when projected to individuals in the back of the room. Letters 3 mm. in size are preferable. In general, the larger the room, the larger the screen used and the further away the projector is placed. For this reason, the same sized lettering on a 3-1/4 by 4 inch slide makes it adaptable for use in most any room.

10. Proportions of a graph will be pleasing if it is drawn about one and one-half times as wide as it is high. This can be varied to meet statistical needs however.

11. Adherence to the simple principles mentioned above will result in the production of slides which, when projected, will give an easily read and readily understandable presentation of data. They should result in a larger amount of knowledge in the possession of the listener.

SOME FACTORS IN HUMAN VISUAL DISCRIMINATION

C. G. Mueller

Several difficulties arise as we attempt to review the data on any human sensory system, its capacity and how the latter applies to military activities. The first difficulty, of course, is that we are not dealing with a capacity, but with many capacities. If we ask the capacity of the human sensory system, we find that it has many capacities depending on the circumstances obtaining when it is used. In fact, the data in any sensory field tell us the extent to which the capacity is dependent upon any one of a large number of variables. Thus, any statement about sensory capacity must have appended to it a statement concerning the circumstances under which this capacity is expected to hold. But if we ask what the eye will be able to do in detecting for example, aerial or surface targets, we shall be answered with a question, what conditions will prevail when the targets are presented? What the eye can do is expressed in terms of figures of certain contrasts, shapes, subtending certain visual angles, exposed for certain times, etc. To make the transition to military targets requires detailed information on the observation conditions. Therefore, to give any definitive answer for military operations, we must know the conditions at the time the discriminations are made. Unfortunately, in many cases little quantitative information is available for specifying combat conditions as far as sensory discriminations are concerned. We know considerably less of the demands made of the human observer in a military situation than we do of the limiting factors in human discrimination.

This deficiency is a serious one. The sensory data show clearly that, discrimination-wise, man can be adjusted to a wide variety of operating conditions. But to make use of this adaptability we must know to what to adapt. For example, the sensitivity to light of a normal observer in outdoor illumination can be improved on by a factor of 10,000 by placing him in the dark for 30 minutes. Thus, the "capacity" which, in this case might be defined in terms of minimum amount of light required to see, is 10,000 times greater if he is adapted to the dark than is the case if he is adapted to daylight brightnesses. Other examples are equally striking. An individual's maximum sensitivity for colored lights can be shifted from a yellow-green to a blue-green; or in the case where we wish to detect a target as brighter than its surrounds, the brightness required for detectability increases by a factor of over 1000 when we adapt to the brightness of a clear daylight sky over that obtained when we are adapted to clear night sky.

To utilize facts such as these requires that we know the demands on the observer. More importantly, these demands must be stated in terms interpretable as sensory data. If we are to predict what the observer will do, operational data such as the voltage of a signal in a radar set or the size of the surface target measured in feet or yards must be supplemented by other relevant data. We must know the brightness corresponding to specified voltages of the signal for the radar screen in question; we must know the distance of the surface target and the visibility conditions expressed in terms of contrast reduction for the case of the surface target. Too frequently the indispensable information linking the stimulus object and stimulus condition at the position of the observer are not available.

A second difficulty arises from the fact that the task of the individual military man is becoming constantly changing. He becomes more and more dependent upon information presented to him by dials and signals and various sensory displays. The fact that the early steps in many combat tasks are being taken over by physical equipment means that the nature of the questions being asked of the sensory psychologist or physiologist is changing.

What might be called questions of the first kind have already been considered. These are generally of the following form: a certain military problem exists, (for example, the detection of surface craft at sea) and the questions raised are what can be expected of the human observer as a detector device, how can be guarantee that he will be performing

optimally, can we improve his performance by training, is it possible to select men who would be good at the specified task? These are the types of questions that were prevalent during World War II; questions of this sort still exist and in great numbers. But in many cases, the first stage of a military task (e. g., target detection) has been, or is being taken over by physical equipment. This does not eliminate the sensory problems (it may even increase them), but it seriously changes them.

Consider an example of the detection of a surface target at sea. If the human observer is used as the detector device, we encounter the problem of the probability of an observer seeing a target and questions of how this probability depends on the size and the contrast of the target. The size and contrast will, in turn, depend upon the range of the target and the contrast will aslo vary with the visibility conditions. After we have answered some of these questions, elementary computations permit us to state the ranges at which certain targets are likely to be seen under various conditions of the physical medium (atmospheric conditions, etc.) and of the observer (the levels of illumination to which he is adapted, etc.). If we now shift to a physical detector, such as radar, the sensory problem, while not eliminated, is seriously changed. The information received by the radar set must now be transmitted to the military operator. If this information is presented, for example, as "pips" on a radar screen then our visual problem is one of determining the probability of seeing the pips and we must be concerned with "optimal" ways of presenting our visual display. But now, instead of relatively simple parameters in the visual detection of sea targets, we must be concerned with visibility under conditions that may change for every change in radar apparatus. In other words, our operating conditions now involve such terms as (1) different speeds of rotation of the scanner; (2) different types of phosphor screens, each with a different decay function, or a different dominant wavelength, etc.

This state of affairs could lead to an endless series of research projects and "solutions" to practical military problems with this latter changing each year with improvements in radar equipment. In fact, this would be true were it not for one fact: that the selection of radar displays can be made dependent upon our knowledge of visual functions. Now the question put to the sensory psychologist or physiologist is of a different form (we shall call these questions of the second kind). Our equipment picks up information about a target. This information is in the form of electrical changes, etc. How should we present this information to the human operator? Should we use a visual signal or an auditory one? If a visual signal, should it be with different colors, different intensities, lights in different positions, etc? Thus, with relatively few restrictions we are asked how we can best use the human observer as a channel and decoder through which information flows and by which it is translated into military action? This represents a significant change in the type of problem confronting us. It goes far in breaking down the questionable distinction between applied and basic data. It means that the practical and applied data in these cases will be the basic data concerning sensory function.

This development just outlined will be mirrored in the present review by an emphasis on what some would call the basic data of vision. How does the eye work and what can the eye do? These questions will be answered in as general a way as possible so that they will have as great an applicability as possible. In the case of each visual function application will be discussed and possible future application indicated.

It is obvious that there are many areas within the military where questions of the first kind must be answered. These areas are no less important because of recent developments in physical techniques. On the contrary, questions of the first kind may become more important because they involve sensory functions for which we have no adequate equipment substitutes. Since we are in a stage of transition as far as the utilization of sensory data is concerned, the review will attempt to incorporate some of the data obtained as answers to specific questions having to do with military performance.

FLUCTUATIONS AT THRESHOLD

The first limitation we encounter in studying the human sensory system arises from an apparently simple phenomenon called threshold. The elucidation of this simple, or obvious, phenomenon and the listing of the variables that affect it, however, will take us far in our discussion of the problems of sensory and perceptual discrimination.

We are led to use the notion of a threshold when we find that a stimulus intensity must reach or exceed a certain range of values before the stimulus can be detected. That there are some stimulus intensities that we cannot see or hear and others that we can seems obvious. But what appears, by inspection, to be a clear dichotomy turns out to be, upon closer examination, a continuous function. This is true both subjectively and objectively. An individual brought into a situation where he must detect near threshold stimuli finds considerable difficulty in deciding whether he sees the target or not. In terms of the individual's behavior the dichotomy also disappears when we find a region of intensity values where the probability of seeing a target is neither zero nor one, but rather varies systematically between these values as a function of the intensity of the stimulus and a number of other variables. Thus, the answer to the question of whether an individual will be able to see a given signal is a probability statement. The answer is that he may or may not and the probability of seeing is a function of a large number of variables which are under our control.

An example of the region of uncertainty for an experienced observer is shown in curve 1 of Figure 1. This figure shows the probability of seeing a short flash of light as a function of the intensity of the light.

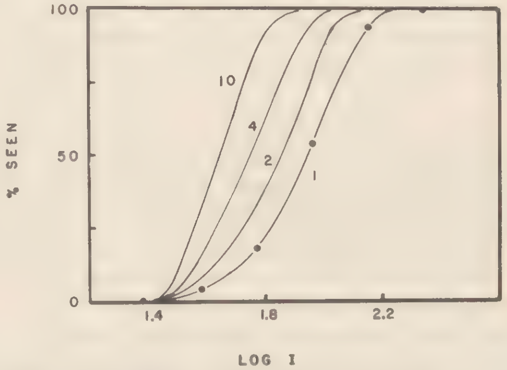


Figure 1. Frequency of seeing as a function of the logarithms of the intensities. Data from (17). Curves 2, 4, and 10 are described in text.

The concept of the threshold and the fact of a range of uncertainty are not limited to the dimension of intensity alone. This region of uncertainty is seen in the detection of difference in intensity, differences in linear extent, contrast, etc. Examples for the case of the detection of a target brighter than its surrounds is shown in Figure 2.

It must be emphasized that the variability at threshold is not the sign of a poor observer. It is not possible to eliminate it by training or other procedures. On the other hand, it may, to a certain extent, be modified. Training may change it, test conditions will change it markedly.

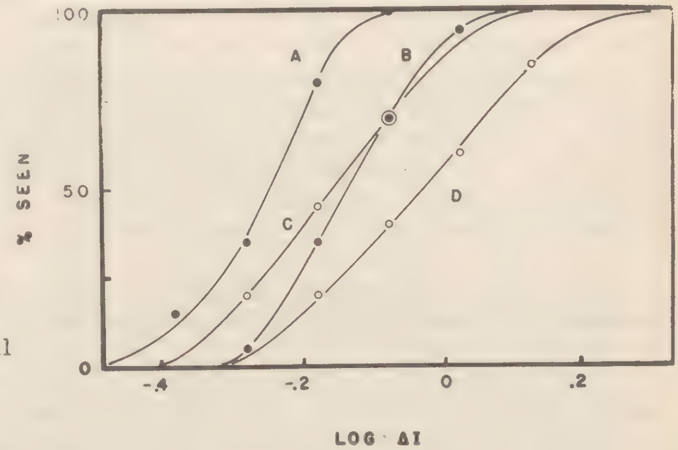


Figure 2. Frequency of seeing as a function of the logarithms of the difference in intensity. Data from (21).

The uncertainty interval in the region of the threshold has many important practical consequences. First of all, we must now realize that threshold is a statistical concept. A threshold is an intensity value (or value of visual angle, or intensity difference) that correspond to some arbitrary point on our probability of seeing function. We recognize then that any use of the human sensory system must also lead to statistical concepts. This is true, for example, if we ask how far an observer can

see under some specified atmospheric conditions. For a human detector, the effective range is a random variable and a single verbal report or instrument setting gives information about instantaneous performance.

Two other points are worthy of mention in discussing the region of uncertainty. The first of these is that the "frequency-of-seeing" curve changes as a function of time. This is shown clearly in Figure 2. Curves A and B were obtained from the same, trained observer on different days. The results for each day are regular and yield a smooth curve. The intensity values for curve A, however, are about twice those for curve B. Both curves were obtained under conditions that minimized change. They were obtained at the same time of day under the same conditions of dark adaptation and under the same test conditions.

The second point to be made concerning the frequency-of-seeing curves is, of course, the differences between individuals. An example of this is also shown in Figure 2, where curves C and D were obtained under the same conditions as A and B, but from a different observer.

The practical consequences of the day-to-day and individual-to-individual variabilities are important. The results for sensitivity fluctuations in time, for example, mean that a night lookout on an hour-on-hour-off watch might be able to see a given target 20 times out of 20 presentations in one watch and 10 times out of 20 presentations on the next watch. The consequence for testing for night lookouts might also be noted. The results mean that there are gross limits to the reliability of any test intrument imposed by the demonstrable changes in the "capacity" being measured.

One of the simplest ways of changing the uncertainty interval, as far as the military is concerned, is to use more than one observer in the detection system. The expected results of such a procedure are shown in curves 2, 4 and 10 of Figure 1. The number on each curve refers to the number of observers used simultaneously as lookouts. The curve shows the probability of at least one observer seeing the target as a function of the intensity. For this graph it is assumed that each individual observer would give the frequency-of-seeing curve shown as curve 1. Here we see that the use of two or four observers changes both the position and the slope of the probability-of-seeing curve. The greater the number of observers used, the greater the change in slope and position. Although not practical, the curve for 10 observers is shown to illustrate this point further.

DARK ADAPTATION

Let us now shift our attention to sensory capacity as it depends on the conditions under which observations are made. These conditions may be in the nature of stimulus variables, such as the nature of the target, or the visibility conditions; or they may refer to the state of the observer, for example whether he is dark adapted, fatigued, or subjected to low oxygen concentration. In general, the changes in capacity to be considered under these headings will be much greater in magnitude than those discussed above.

Perhaps the greatest changes in sensitivity are to be found in the variations due to "adaptation" conditions so we shall begin with a discussion of dark and light adaptation.

Dark adaptation is a term referring to the changes in sensitivity of the eye as a function of time in the dark. An example of these changes is shown in Figure 3. This figure shows how the threshold intensity varies with time in the dark. The thresholds represented by the beginning and end of the dark adaptation curve differ by a factor of 10,000. Actually, of course, the curve of dark adaptation is not always the same and we shall see presently the extent to which variables such as size of target, exposure time, and previous light

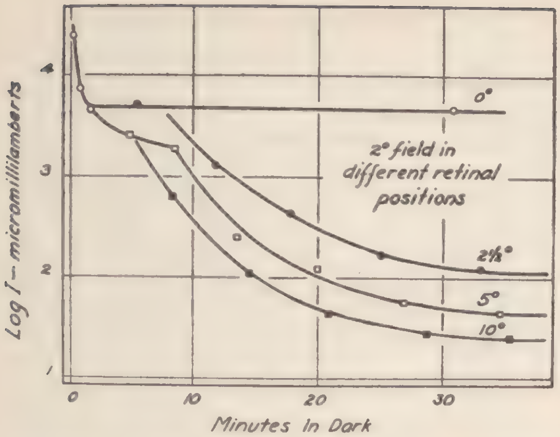


Figure 4. Curves of dark adaptation to a 2° stimulus fixated centrally and at $2\frac{1}{2}^{\circ}$, 5° and 10° peripherally (15).

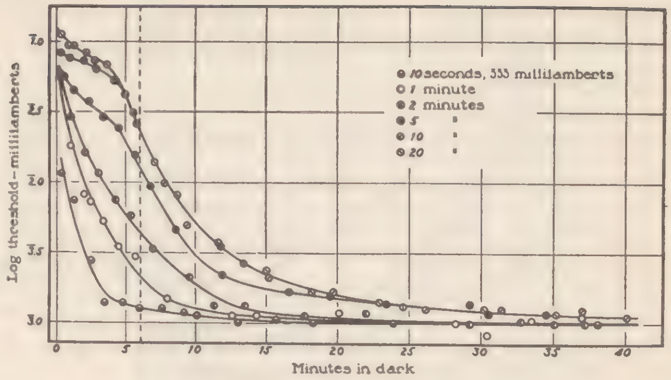


Figure 3. Dark adaptation curves for various durations of the previous light adaptation(29).

adaptation affect this curve. Some of these variables will affect the shape of the curve, that is how much the sensitivity changes or how rapidly it changes. Other variables will affect only the position of the dark adaptation curve on the intensity axis.

Let us consider first the variables that affect the shape of the dark adaptation curve. Figure 4 shows the way in which position of the test target affects the dark adaptation curve. These curves were obtained for a 2° field fixated centrally and at $2\frac{1}{2}^{\circ}$, 5°, and 10° peripherally. These curves show that for a constant area stimulated, that is, for a fixed size of target subtending 2° of visual angle, the threshold varies systematically with changes in the angle of regard. For the centrally fixated target, we observe no discontinuity in the dark adaptation curve. For all other positions, a break in the curve is observed and the more peripheral the target, the greater the displacement of the curve to the lower intensity values.

Let us now ask how the position of the target changes the sensitivity at complete dark adaptation. To obtain the answer, we can take the values shown in Figure 4, after 30 minutes dark adaptation, i. e., we can cut through all of the curves at 30 minutes. As we would expect by inspection of Figure 4, such an analysis shows that the eye is more sensitive in the peripheral region than in the fovea or centered area. Recently Sloan has studied this problem in detail and her results are also shown in Figure 5. The results show that the eye is most sensitive in a region 10 to 20 degrees from the center. The difference in sensitivity between the 10-20 degree region and the foveal region is of the order of 10 to 1 for the Sloan data and 50 to 1 for the Hecht, Haig and Wald data of Figure 4.

The effect of retinal position on a dark adaptation curve depends upon several other variables, the most important one being the wavelength or, more properly, the frequency of the test stimulus. That this is the case is shown clearly in Figure 6. If we use a deep red light and perform the experiment represented in Figure 5, we find no break in the dark adaptation curves regardless of the position of the stimulus. In other words, for a deep red stimulus we obtain the top curve of Figure 5,

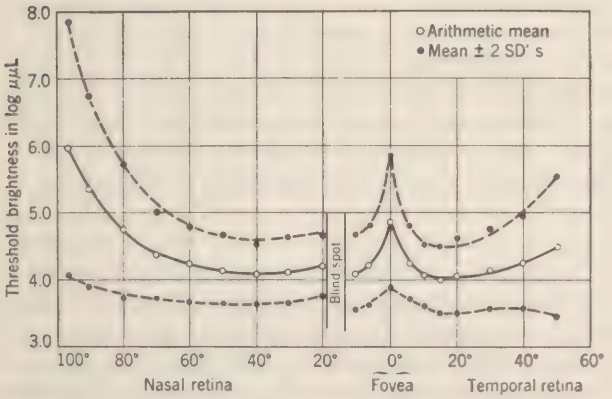


Figure 5. Brightness threshold for the dark adapted eye as a function of the position of the stimulus [(7), data from (28)].

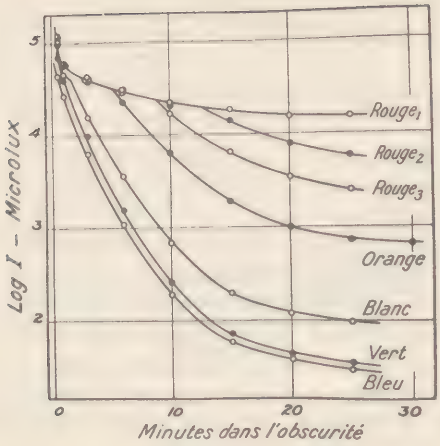


Figure 6. Curves of dark adaptation for various dominant wavelengths of the test stimulus (14).

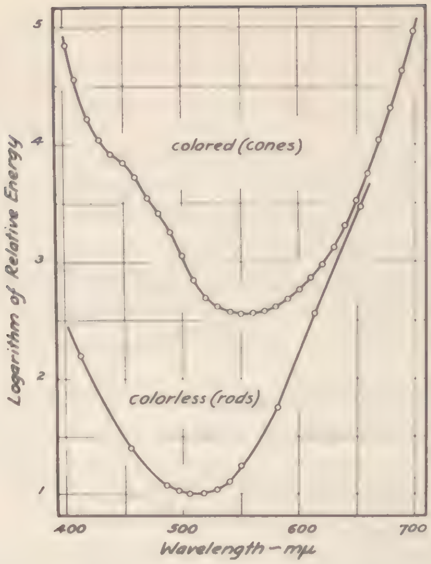


Figure 7. Sensitivity as a function of the wavelength of the test stimulus (16).

for all positions of the target. If we use any colored lights, from the red-orange region of the spectrum to a deep blue, we observe a break in the curve with the magnitude of the break depending upon the wavelength of the stimulus.

The curves for dark adaptation as a function of wavelength are deceiving in several respects. In terms of the amount of energy required for threshold the human observer is not most sensitive to the violet end of the spectrum although the curves of Figure 6 might give this impression. We obtain Figure 6 if we do one of two things (1) measure the threshold in relative energy units and then translate all curves so that the first portions of all curves coincide, or (2) use an intensity unit that performs this operation for us. The measurement of dark adaptation curves for various wavelengths in energy units give rise to curves differing in position on the energy axis as well as in shape. If we cut across such curves after two or three minutes of dark adaptation and plot the energy values at threshold as a function of wavelength, we obtain the top curve of Figure 7. If we now cut across the same dark adaptation curves after 40 minutes of adaptation we obtain the lower curves of Figure 7. What is shown in Figure 6 is the measurement of dark adaptation with an intensity unity based on the upper curve. What results, of course, are curves that are invariant with change in wavelength for the first few minutes and that decrease beyond this time by amounts that correspond for each wavelength with the difference between the two curves of Figure 7. Thus, the dark adaptation curve for red light shows little, if any, decrease beyond the first rapid portion of the curve, the blue and violet curves show the greatest decrease. What must be emphasized, however, is that the human observer at all times in the course of dark adaptation required more energy to see a violet light than is required for a green or yellow light.

The existence of the two sensitivity functions shown in Figure 7 has important applications. The most widely known is the use of red light to obtain maximally effective illumination for photopic or cone function while minimizing the effect of the light on scotopic, or rod function. The use of red goggles in ordinary room illuminations or the use of red filtered light sources in briefing rooms gives a brightness adequate for reading maps, for example, and yet provides a brightness for the scotopic system that does not seriously impair peripheral dark adaptation. The superiority of red light over white light in this selective use of the photopic system is made possible by the difference in the sensitive curves of

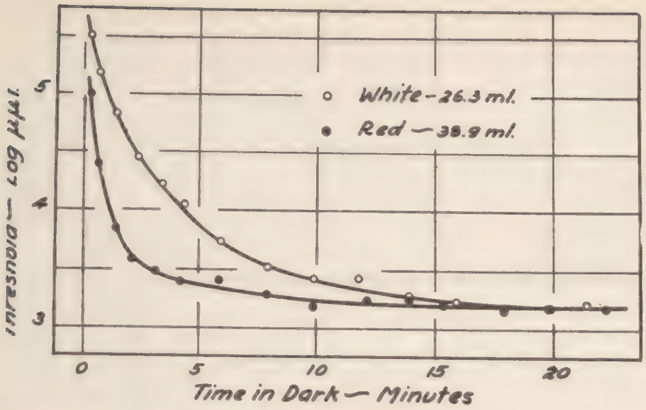


Figure 8. Dark adaptation following exposure to white or red light of approximately equal photopic brightness (16).

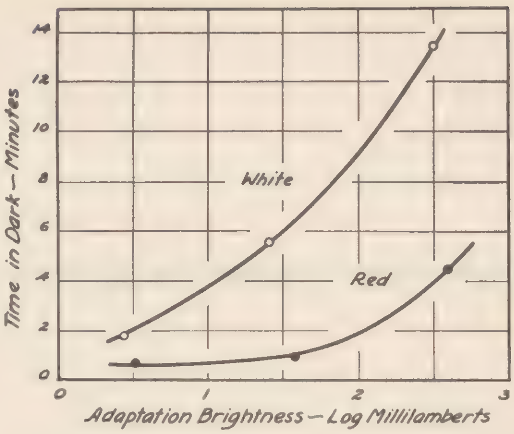


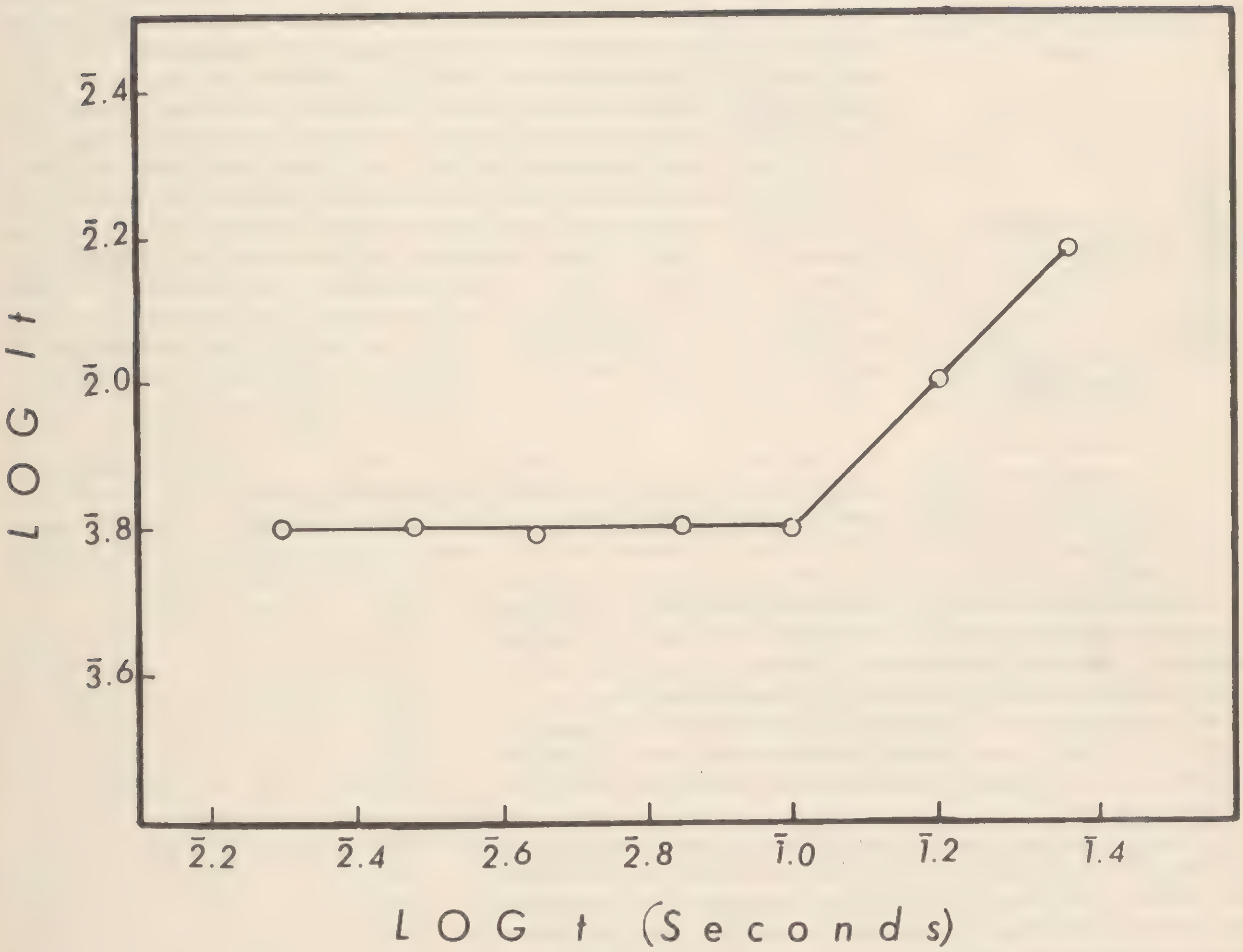
Figure 9. Time required to dark adapt as a function of the photopic brightness of a white or red preadapting stimulus (16).

Figure 7. As Figure 7 clearly shows the advantage of red light is not due to the higher threshold of the scotopic system for the red end of the visible spectrum. In fact, the threshold for red light is about the same for both photopic and scotopic activity. What is important are the thresholds for the other wavelengths. A red light of fixed energy will have approximately the same effect on both the photopic and scotopic systems. A white light of fixed energy will have a greater effect on the scotopic than on the photopic system. Thus, a white light and a red light matched for brightness with the cones will not appear matched for the rods. This modified version of the Purkinje phenomenon is the basis for the advantage of red goggles. When we make a white light intense enough to be as effective as a red light for reading and other tasks, we do more damage to rod dark adaptation than is done with the red light.

That this general argument is valid is shown conclusively in an experiment by Hecht and Hsia. Dark adaptation was studied after adaptation to white light and after adaptation to red light of the same photopic brightness. The curves obtained under these conditions are shown in Figure 8. The data represent the averages from ten experimental sessions. It is obvious that the eye is more sensitive and recovers more rapidly after adaptation to the red than after adaptation to white light. Hecht and Hsia also obtained these functions at various intensity levels. The superiority of red light is less pronounced at low intensities where the recovery from both is more rapid. Figure 9 shows a plot of the time required to dark adapt to an arbitrary threshold value after adaptation to various intensities of either the red or white light.

Two other variables in the discussion of the target are important in specifying the sensitivity of the eye; these variables are (1) the length of time the target is exposed, (2) the subtense area of the target at the eye. Both of these variables affect the position of the dark adaptation curve on the intensity axis.

For the relation between exposure time and intensity there are two rules to remember. For short exposure times the eye is a perfect summator and the product of intensity and exposure time must reach or exceed a fixed constant value for detection. Since intensity is a rate measure this means that, for short exposure, the energy required for threshold is a constant, regardless of exposure time. For long exposures the threshold depends only upon the intensity, that is, the threshold is independent of exposure time. For small stimulus areas, the transition from one of these rules ($\underline{I} \cdot \underline{t}$ = constant) to the other ($\underline{I}$ = constant) is extremely abrupt. An example is given in Figure 10, where log $\underline{I} \cdot \underline{t}$ is plotted against log $\underline{t}$. In this plot the first rule ($\underline{I} \cdot \underline{t}$ = constant) calls for a straight line of zero slope; the second rule requires a straight line with a slope of unity. That both relations hold is clearly shown. For large areas of the stimulus the transition from one of these rules to


$\bar{2}.4$
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LOG It
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LOG t (Seconds)

Figure 10.

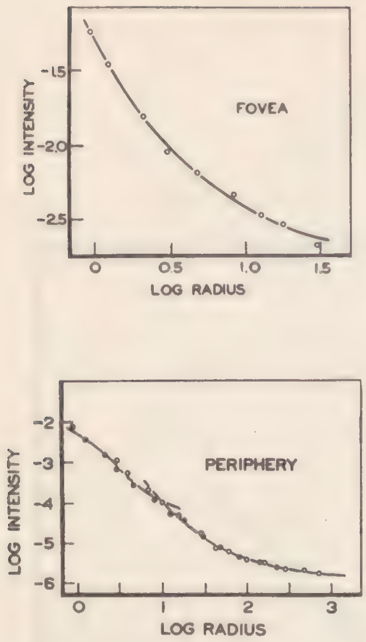

Figure 11. Threshold intensity for the fovea and periphery as a function of the radius of the circular test field (10).

the other is more gradual and there is a range of exposure times over which neither law holds. In general, then, for short flashes energy is the important dimension; for long flashes intensity, or rate of flow of energy, is the important dimension.

The importance of the area of the target is shown in Figure 11, where the threshold intensity is plotted against the radius of a circular target. The upper curve was attained for foveal stimulation, the lower curve with the stimulus 20° in the periphery. The peripheral curve suggests a practical rule that the product of area and intensity is a constant for most of the range of the areas. There is a systematic deviation from this rule for the larger areas. This deviation is important for theories of visual function but it is not likely that stimulus areas of military significance will go beyond the range covered by the rule. For the fovea the product of area and intensity is also a constant for small areas, although the deviation for larger areas is more pronounced than in the periphery. In general, for both fovea and periphery there is a diminishing return for increasing the energy by increasing the area, although for a fixed brightness of the target, the larger the area the greater the probability of seeing.

In the case of increasing the area of centrally fixated targets we are likely to involve two variables, one is a "pure" area variable, the other is the position variable discussed above and shown in Figure 6.

Another variable of possible importance for selection purposes is the variation in threshold with the age of the observer. The function relating threshold and age has recently been studied by Robertson and Yudkin and is shown in Figure 12. There is an increase in threshold of .10 to .15 log units (or an increase of from 25 to 40 per cent) for every ten years of age between 20 and 70. In a general way, these are supported by the work on night vision testing during World War II which shows a greater percentage of failures on night vision tests for the older age groups. Robertson and Yudkin have also shown that most of the variation of threshold with age can be accounted for by the change in the size of the dark adapted pupil with increasing age.

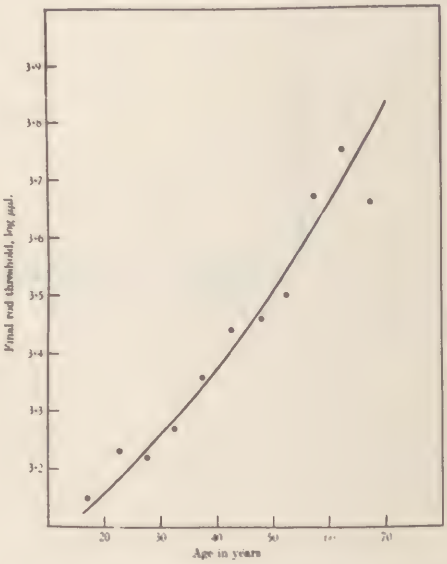

Figure 12. Threshold brightness as a function of the age of the observer (24).

One final class of variables that we shall consider and that has a profound influence on adaptation to dark is the intensity and duration of the stimulus before dark adaptation begins. The results referred to in Figure 3 give an example of the changes in dark adaptation curves obtained by changing the duration of the preadapting stimulus. In this connection there are two important findings to consider. The first is obvious in the light of our previous discussion; this finding says that the greater the intensity of light and the longer it is on before dark adaptation begins, the higher is the initial threshold and the longer it takes for the eye to adapt to any pre-assigned threshold value. Over a large range of values of both intensity and duration of the pre-adaptation stimulus, we find again a rough rule that the product of intensity and duration must equal a constant to give a constant effect measured by the subsequent dark

adaptation curve. This means that we get the same dark adaptation curve if we adapt to bright light for short time or adapt to dim light for long time provided the product of the intensity and the exposure of the adapting light is a constant.

This $\underline{I} \cdot \underline{t}$ relation for adapting stimuli does not hold for extreme values of intenstity and duration and the second important finding is what happens to dark adaptation under these extreme preadaptation conditions when the reciprocity of intensity and duration of exposure breaks down. For very short periods of preadaptation the recovery in dark adaptation is rapid and this can be exaggerated to such an extent that one curve may start at a higher initial threshold but drop sufficiently rapidly so as to cross a dark adaptation curve with a lower initial value. Practically, this means that the effect, for example, of a momentary stimulus, such as a visual signal, gunflash, etc., will disappear more rapidly than the same energy distributed over a longer period of time. For low to moderate intensities, such as would be encountered in most visual signals, recovery should occur in less than one minute and probably within 10 -- 20 seconds.

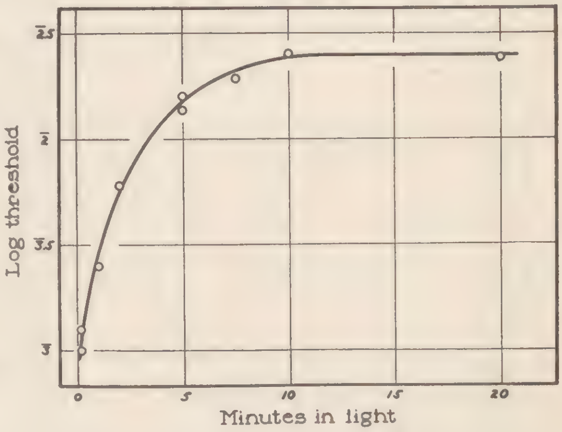

Figure 13. The relation between threshold intensities (after 6 minutes in darkness) and the duration of the previous light adaptation (29).

We have said little about light adaptation and for very good reason. Relatively less is known about this important process than about dark adaptation. Much of our information concerning light adaptation comes from the family of curves of dark adaptation shown in Figure 3. Light adaptation refers to the change in the threshold as a function of the length of time we are exposed to a stimulus. If we define light adaptation in terms of the threshold immediately after the adapting intensity is reduced to zero, it is obvious that the measurement of light adaptation is, in effect, the measurement of the beginning of the dark adaptation curve. We are then interested in how the beginning of the curve varies with the intensity and duration of the previous exposure. There are certain limitations to such a restrictive definition of light adaptation. As shown in Figure 3, the shape as well as the starting point of the dark adaptation curve is a function of the duration and intensity of the previous exposure. We have seen that it is possible to obtain dark adaptation curves that have the same starting point (instantaneous threshold) but different rates of decrease. This means that if we measure the effect of light adaptation by measuring the threshold one minute after turning off the adapting stimulus we shall obtain a different function than one measured in terms of threshold immediately after, or 30 seconds after the cessation of the adapting stimulus. One example of the type of curve obtained is shown in Figure 13. In the light of the previous discussion it may be considered illustrative, but the quantitative characteristics of the curve will change with the criterion measure of light adaptation.

INTENSITY DISCRIMINATION

We have been discussing variables that affect the threshold of the human eye in the dark. Actually, of course, most situations in which we are asked to detect a target have some light present, that is, we see a target against a background. This is true of all daytime operations, of all equipment room tasks and to a certain extent even of night lookout where silhouetting against the sky is possible. It is of interest to ask the extent to which the rules given for the detection of a target in the dark apply also to cases where we are detecting a figure against a background. In general, the answer is that the same rules do apply, but it is instructive to indicate the similarities and differences in functions for zero and supra-threshold intensity levels.

We have already had occasion to refer to the fact of response variability at threshold for intensity differences. This variability is similar in many respects to that observed for absolute threshold. Figure 2 shows the probability of seeing a difference in intensity as a function of the magnitude of the difference.

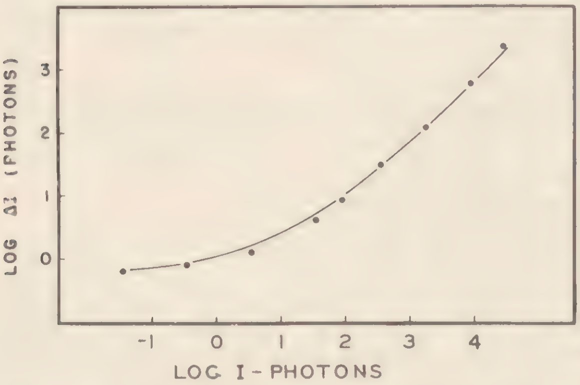

Figure 14. Magnitude of the difference threshold for various intensities of the adapting stimulus Data from (21).

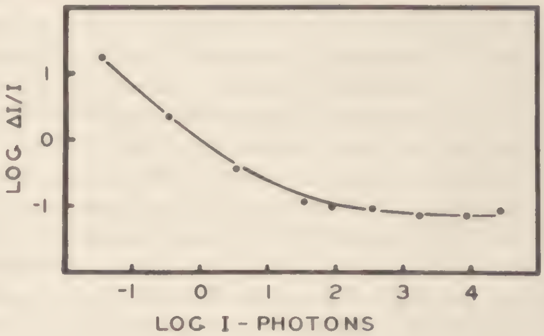

Figure 15. The relation between threshold contrast and the background intensity (21).

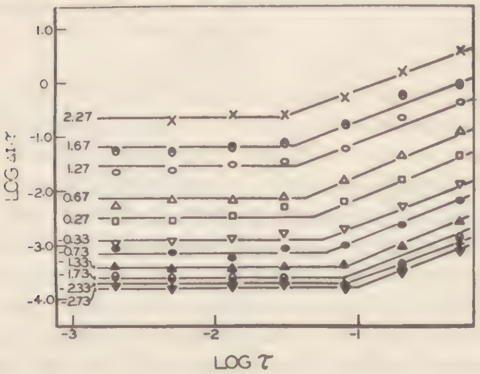

Figure 16. The amount of added energy required for stimulus detection for various durations of the stimulus (11).

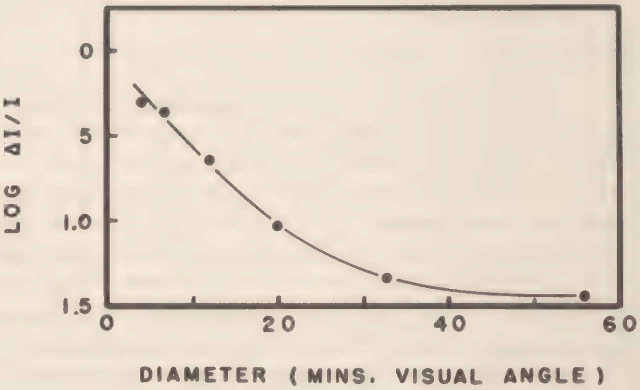

Figure 17. The relation between threshold for intensity discrimination and the diameter of the test field (9).

The first new variable we encounter in the detection of a target against a background is the intensity of the background. If we consider the amount of intensity that must be added to a region of the background in order to see the region as brighter than its background, we find that the threshold addition of intensity varies with the background intensity as shown in Figure 14. If we define contrast as the ratio of the difference in intensity to the background intensity then contrast sensitivity increases (that is, threshold contrast decreases) as we increase background intensity. This is shown in Figure 15. This function has recently been extensively investigated by Blackwell who obtained the same relation although his curves are based on many more observations. These results mean that for a fixed intensity of the signal the lower the background or noise intensity the greater the probability of detection. For a fixed contrast or ratio of signal-to-noise intensity, the greater the background intensity the greater the probability of detection.

We find, as in the case of absolute threshold, that area and exposure time affect the threshold for contrast or for intensity differences. Figure 16 is the analogue of Figure 10 and shows $\underline{\Delta I} \cdot \underline{t}$ as a function of log $\underline{t}$ for several levels of adaptation intensity.

Figure 17 shows the relation between the added intensity required for detection and the size of the target. Once again, over moderate ranges of area the product $\underline{\Delta I}$ · $\underline{\text{Area}}$ is a constant although there are systematic deviations for large areas and these deviations are important for visual theory.

In addition to the intensity of the immediate background of the target we must be concerned with the intensity of any surrounding area if this is different from the background. Consider a stimulus field shown in Figure 18 which is typical of what might be found in radar reading rooms where A can be considered the radar screen, a the pip to be detected and B, the area surrounding the radar scope. In a situation of this sort the threshold for detection of a as different from A depends not only on the brightness of a and A but on the brightness of B, the surround field. The results of one experiment are shown in Figure 19. This figure shows that optimal sensitivity (minimal difference threshold) is obtained when the surround brightness is equal to the brightness of A. Undoubtedly, this effect depends on many other variables, particularly the size of A and B and these variables should be exhaustively studied.

Figure 18. See discussion in text.

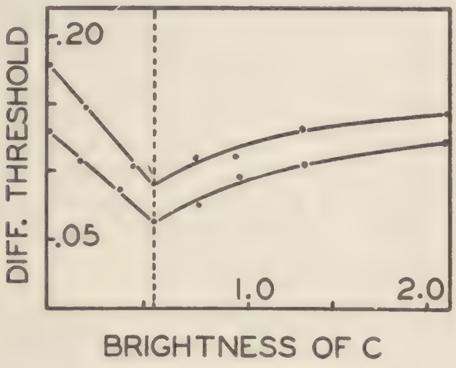

Figure 19. The difference threshold for various brightnesses of the surrounding field. [(3), data from (8)]. The C refers to the background of the figure used. It is equivalent to B in Figure 18.

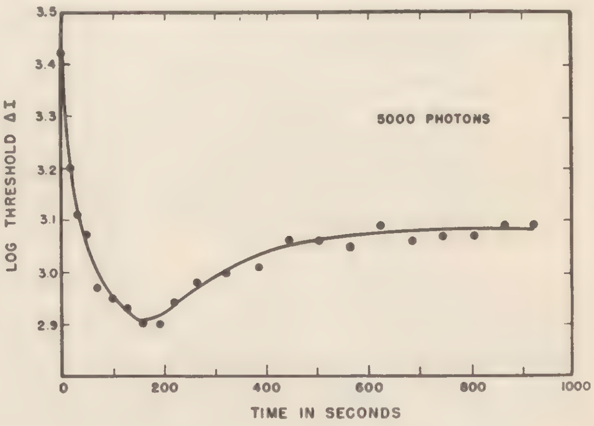

Figure 20. The relation between the threshold for an intensity difference and the length of time the observer has been adapting to the background intensity (1).

The topic of visual fields surrounding acuity objects, contrast objects, etc., requires more emphasis both experimentally and theoretically. The area surrounding the test object has been used to stabilize variability, to eliminate the inversions in acuity, flicker, and intensity discrimination functions at high intensities with little attention directed toward how and why this operation works. The importance of the surrounds comes up again and again in military problems where visual displays are heterogeneous.

The results for intensity discrimination considered thus far have been obtained with the eye adapted to the background intensity. Our discussion of dark and light adaptation suggests that the length of the adaptation period may be a variable. Figure 20 shows the change in $\underline{\Delta I}$ as a function of how long the observer is adapted to the background. These results were obtained with high intensities of the adapting stimulus (5000 Trolands). The figure shows a rapid decrease in threshold for $\underline{\Delta I}$ for the first three minutes and a subsequent increase in the threshold that is not complete until ten minutes of adaptation. Comparable results for

lower intensities of the adapting stimulus show that the required increment in intensity decreases rapidly in the first two minutes of adaptation and then remains relatively constant.

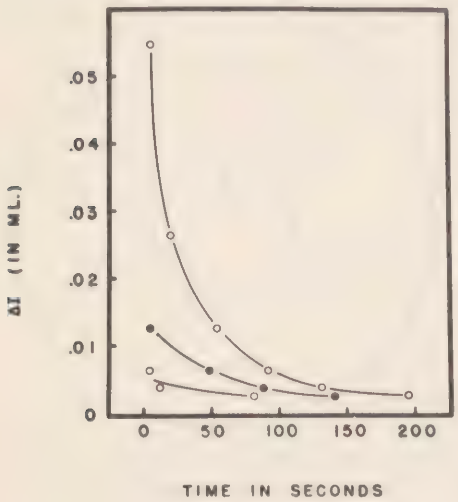

Figure 21. The difference threshold as a function of the length of time the observer has adapted to the background brightness. The three curves represent (from top to bottom) decreasing brightnesses of the previous adapting stimulus. Data from (13).

The change in the difference threshold ($\underline{\Delta I}$) when the background intensity is decreased (rather than increased from zero as in the previous case) is shown in Figure 21. Here the value of threshold $\underline{\Delta I}$ is plotted as a function of time of adaptation to the decreased intensity. The parameter represented by the three curves is the intensity of the previous adapting stimulus.

The data on intensity discrimination have very wide application. Virtually all visual tasks involve the discrimination of intensity differences. In addition, measurement of sensitivity in the dark may be considered a special case of intensity discrimination where the background intensity is zero. It is probably also true that much of what is normally called visual acuity is an intensity discrimination function.

Two important areas of application are those having to do with camouflage and with visibility conditions in radar operation. Some of the applications to radar operation may be indicated. If you have the screen brightness and signal brightness under separate control then (1) for fixed screen brightness the greater the signal brightness the greater the probability of detection (2) for fixed signal brightness the lower the screen brightness the greater probability of detection. If we have control only over contrast (signal to noise ratio) then the higher the noise the greater the probability of detection.

The application of the adaptation effects in intensity discrimination are numerous and, in fact, the results of Figure 21 were replotted from a study on radar screen visibility. Consider the situation in which an observer comes into the radar room from a place of higher brightness. If we can control the brightness of the signal, the greater the signal the more rapidly will the target be picked up. If we have control only over contrast the greater the background intensity (noise level), up to intensity to which the observer was previously adapted, the more rapidly the detection.

In both cases, the time required to detect a given target will be greater, the greater the difference between the illuminations. Figure 20 and similar curves for different brightnesses give the results for the case of going from dark to higher illuminations. Figure 21 gives the results for the case of going from a brighter to dimmer region.

Additional applications of intensity discrimination data may be seen in the area of camouflage. A simple example may be found in one attempt to camouflage aircraft. If concealment from aerial observers is the goal we wish the plane to be indiscriminably different from its background which will be land foliage or sea surface. If concealment from ground observers is desired then the plane must not appear different from the sky. In the latter case for daytime operation the target usually appears as darker than its background, i. e., the plane is usually silhouetted against the sky except in cases of different reflection of the sun. To avoid detection the plane must be made to appear brighter and to approximate the brightness of the sky as closely as possible. One attempt to increase the brightness of the plane involved the mounting of light sources in the wings of the plane.

Similar principles were employed in camouflaging aircraft for night flying. Under circumstances where the brightness of the night sky is the only brightness to be considered there is no problem of camouflage. The plane-sky contrast for low levels of brightness is below threshold for the size of the target involved. For the dark adapted eye, however, very little light from a target is required for detection, and, in the presence of additional light source, such as enemy searchlights, the reflected light even from low reflection surfaces will exceed threshold. One of the solutions of this problem involves a calculated risk. One way of achieving very low reflection values is to observe a specular reflector from a point not included in the ray paths of the reflected beam. This principle was used on some of the night fighters in World War II. The plane surface was covered with a paint that approximated a directional reflector. Rays from any point source such as a searchlight were reflected in a direction that depended on the orientation of the reflecting surface. Because of the curved surfaces of the aircraft this meant that the full plane was never seen although at any moment small streaks of light might be seen due to reflection from some part of the craft. These flashes would be detectable but would not trace out any identifiable shape.

VISUAL ACUITY

Acuity indicates the ability to see fine detail and is defined as the reciprocal of the minimum visual angle (expressed in minutes of angle) separating two contours. The first requirement for measuring visual acuity is that we have a target different in brightness from its background. The size of the target, or some portion of it, is then systematically manipulated to determine the minimum angular size required for detection of some critical characteristic of the target. Consider the broken circle target shown in Figure 22. The magnitude of the break in the circle is systematically varied until the observer is unable to see the break. Many other types of acuity objects can be used and two others are shown in Figure 22. Perhaps the most frequently used for testing purposes is the block letter found in many tests of acuity. Frequently a grating object or a checkerboard design is used.

The type of acuity object used will affect measurement in several important ways and these effects can be shown most clearly by first considering the way in which acuity varies with intensity. Figure 23 shows a plot of visual acuity against intensity of the background. In general, acuity increases as the background intensity increases. Curve C shows results for a Landolt ring target; the second curve in the figure gives the results for a grating target. Acuity for the Landolt ring reaches a higher value at the highest intensities than is the case for the grating target. In general, acuity values are greater at the higher

Figure 22. Representative targets for testing visual acuity.

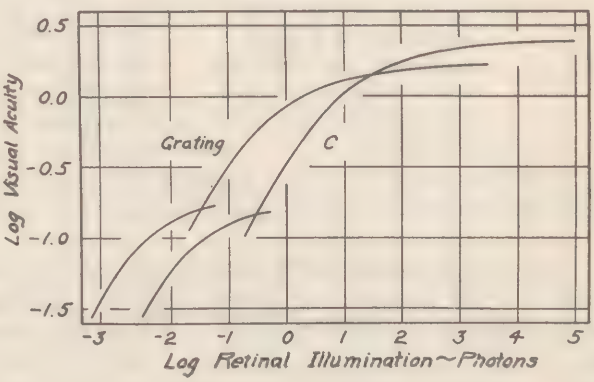

Figure 23. The dependence of visual acuity on the intensity of the background for two test targets (27).

intensities for targets that do not involve repeated patterns. The detection of a bright thin line on a dark background is more likely than the detection of non-uniformity in a field of alternate light and dark lines of the same dimensions.

Thus, acuity depends on the intensity at which it is tested, and this intensity function in turn depends on the type of target used. Even when we restrict ourselves to a single type of target, e. g., the resolution of two thin lines, we find that the acuity-intensity function is not simple. The results show that a bright target on a dark background gives a different acuity-intensity curve than does a dark object on a bright background. These results appear in Figure 24. The upper curve was obtained using a dark target against a light background; the lower curve refers to a similar experiment with a light target against a dark background. The lower curve shows a decrease in visual acuity at the highest intensities. To complicate the situation further these results seem to depend on the size of the lines to measure acuity. If the two lines are narrow (168 seconds of visual angle), we observe the decrease in acuity at high intensities; if the lines are larger (1000 seconds of visual angle) we observe no decrease over the range of intensity studied. These results are shown in Figure 25. We have said that the requisite condition for measuring acuity is a target that is different from its background. The extent to which it is different is an important parameter of acuity function. One measure of this difference is the target-background contrast and the results show that the greater the contrast the greater the visual acuity, or the smaller the visual angle required for detection.

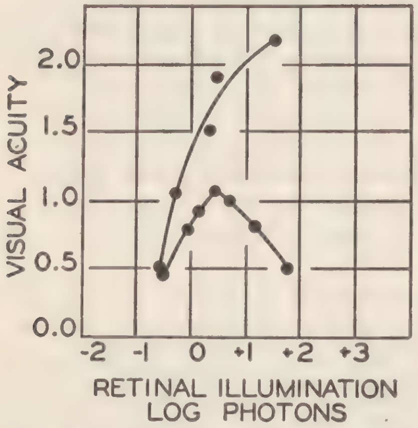

Figure 24. The visual acuity-intensity function for two conditions of contrast. The upper curve was obtained with a dark target on a bright background, the lower curve with a bright target on a dark background [(3), data from (30)].

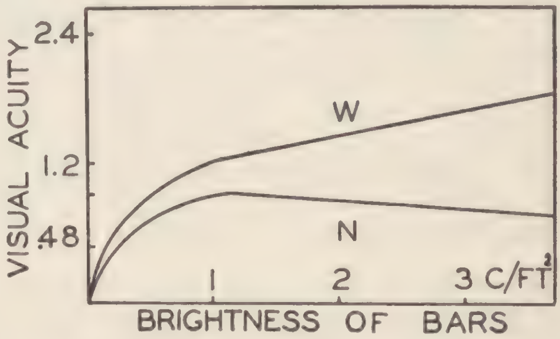

Figure 25. The dependence of the acuity-intensity function on the thickness of the testing line [(3), data from Fry and Cobb].

As in the case of the thresholds for intensity and intensity difference, the visual acuity varies with the time during which the target is exposed. Figure 26 shows the results of one study of this relationship. Over the ranges of exposure times and intensity employed in this experiment the logarithm of the angular width of line required for detection was a linear function of the logarithm of intensity. Also, the product of visual angle and exposure time was constant for a threshold effect.

For high levels of illumination the region of maximum visual acuity for the human observer is the central or foveal region, and all of the results discussed so far have been obtained using central fixation. A recent experiment showing the validity of this general rule yielded the results shown in curve A of Figure 27. Here we see visual acuity plotted against retinal position expressed in degrees from central fixation. At low levels of illumination the periphery of the eye is more sensitive than the fovea which raises an important question concerning the relation between visual acuity and retinal position at low illuminations. The answer to this question may be seen in Figure 27. The superiority of central fixation decreases steadily as we decrease intensity until at the lower intensities the region

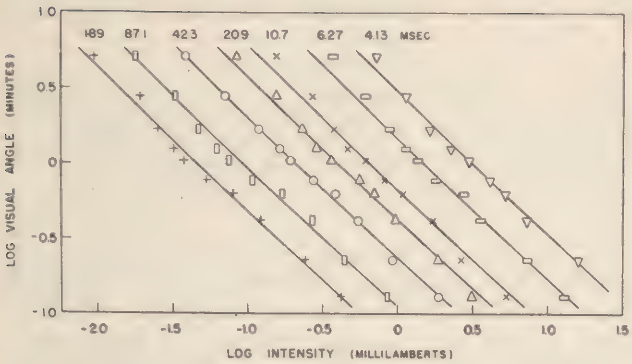

Figure 26. The acuity-intensity functions for various exposure times of the test figure (23).

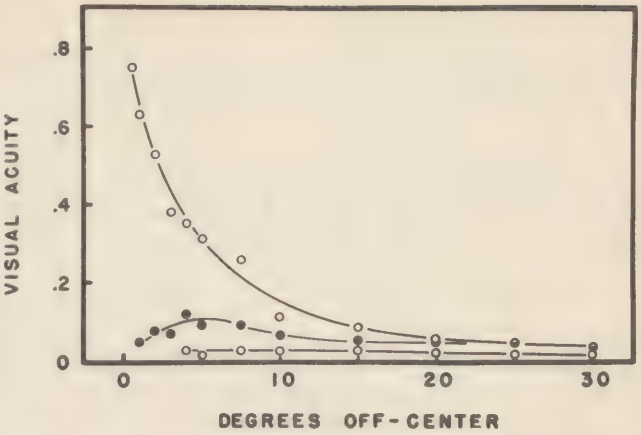

Figure 27. Visual acuity as a function of retinal position for three background brightnesses. The curves (from top to bottom) were obtained at 9, 6.3, and 4.6 log micromicrolamberts. Data from (20).

5 to 10 degrees from the center gives maximum acuity values. These results and others not shown in the figure indicate that the point of maximum acuity varies systematically with the background intensity, shifting gradually from the center (0°) to a position 10° or more in the periphery.

Two types of acuity objects may deserve special mention in connection with military operations and testing. The first of these is a vernier acuity object that requires alignment of two lines, edges or borders. This acuity function may be important for the many military tasks involving reading of dials, pointer directions, etc. The second type is a letter or numeral acuity object which again may be linked to reading of dials, maps and charts. In addition, many feel that letters or numerals measure a more complex acuity function and therefore may be of greater practical use to the military as a test object.

The data for vernier acuity follow closely those for other acuity objects. The effect of background intensity is shown in Figure 28 and in curve A of Figure 29 where again acuity is seen to increase with increasing intensity. Figure 28 also exemplifies the decrease in acuity with decreases in exposure time, although the complete function has not been studied. Increasing the separation between the two targets to be aligned decreases vernier

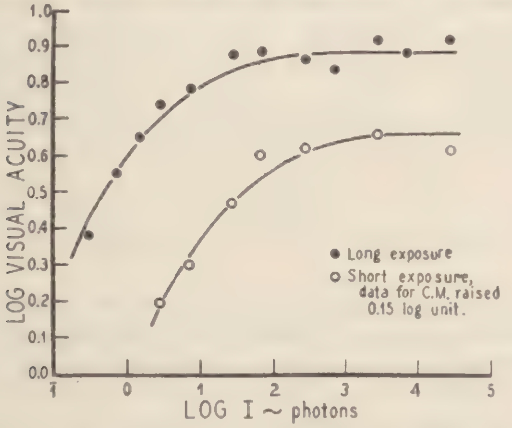

Figure 28. The relation between vernier acuity and intensity for two exposure times (2).

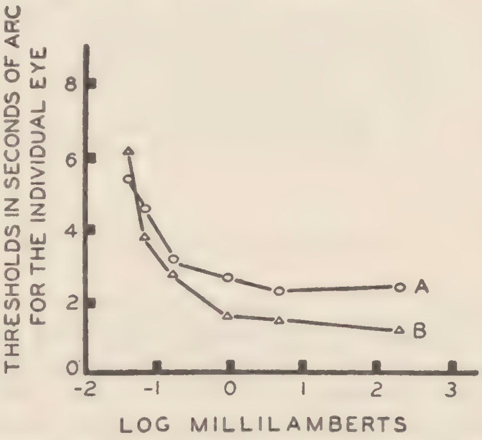

Figure 29. Vernier acuity (A) and real depth acuity (B) as a function of background brightness (6).

acuity and this finding is shown in detail in Figure 30. Vernier acuity is more sensitive to target separation than, for example, stereoscopic acuity. The width of line used in vernier adjustment seems to be unimportant.

Much work has been reported on the detection of letters and numerals and this information should be taken into account in considering a letter or numeral target for testing purposes. We shall have occasion to refer to the testing problem later. Let us briefly consider first some of the variables that influence letter and numeral detectability.

In addition to the variables already mentioned for acuity targets in general, variables such as contrast, size exposure time, etc., we encounter additional variables with letter and number displays. One such variable is the stroke width of the letter or numeral. The relation between visual acuity and stroke width of the figure (of constant height) is shown in Figure 31. For the small angles involved the distance at which a target is detected is directly proportional to visual acuity so the ordinate in this figure may be considered to be visual acuity in arbitrary units. The lower curve shows the results for a dark target on a light background, the upper curve shows the results for a white figure on a dark background. Once again we find that the direction of contrast is an important variable. It affects the numerical values of acuity obtained and the value of the maximum stroke width.

When more than one number or letter is presented simultaneously, the spacing of the figures becomes an important variable. The results of Berger indicate that there is an optimal spacing for figures and that this optimum depends on the nature of the figure.

Space does not permit complete coverage of the many variables that have been studied. One final variable that must be taken into account in the use of letters and numbers either in testing or as indicators or signals is the inequality in the difficulty and the confusability of the figures. Under fixed conditions of width of stroke, height of letter, contrast, etc., all of the letters are not equally difficult. In addition, if a given figure is presented and an observer guesses incorrectly, all of the possible errors (25 in the case of the letter) are not equally likely. He is not as likely to say W when he is presented a T as he is to say I or L. Once again the difficulty of the items and the confusability of the items have important practical consequences.

It must be obvious, from this brief review, that visual acuity is not a fixed capacity of the observer. The capacity will depend on the condition of the observer, the type of material we present, and the way in which we present it. In some limiting cases we may be restricted by the resolving power of the optical system (cornea, lens, fluid media). In other cases we may be limited by the resolving power of the retina and its mosiac structure. In fact, in all cases performance must be limited by the contrast rendition of both of these. The extent to which the sensory system will react and transmit the characteristics of the stimulus will depend on the variables briefly referred to and many others.

STEREOSCOPIC ACUITY AND THE DISCRIMINATION OF REAL DEPTH

Stereoscopic acuity has had its greatest application in range finders for anti-aircraft firing, surface firing at sea, and to a lesser extent in artillery firing. The theory of stereoscopic vision is well developed and data on many variables are available.

Figure 32 shows the effect of intensity on the variability of depth settings in an artificial range finder situation. The magnitude of the error, measured here in terms of the average error, decreases with increasing intensity.

The effect of increasing the distance between the adjustable ranging line and the target is shown in Figure 33. The results show that the average error in making range settings

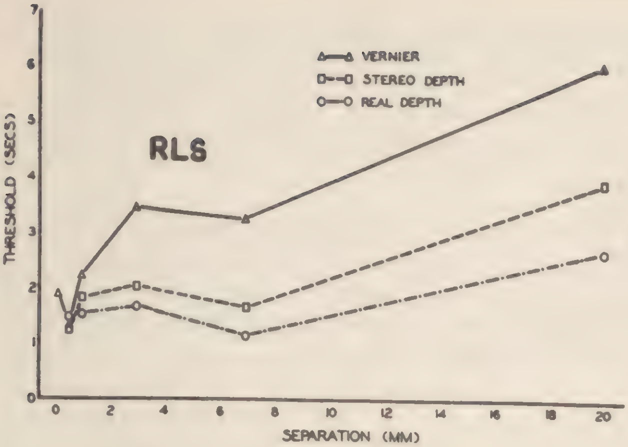

Figure 30. Vernier acuity, stereoscopic acuity, and real depth acuity as a function of the separation between the target and the reference line (5).

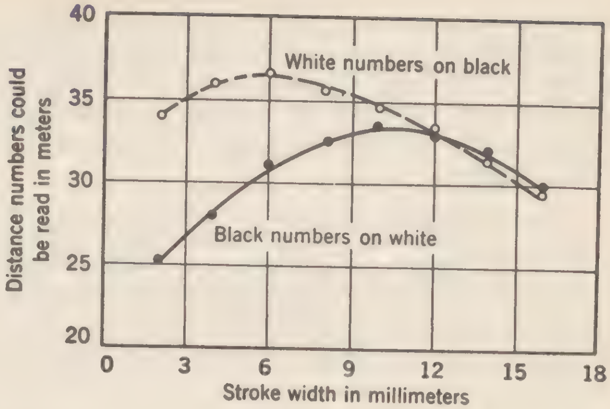

Figure 31. The distance at which numerals can be identified as a function of the stroke-width of the numerals and for the contrast conditions [(7), data from (4)].

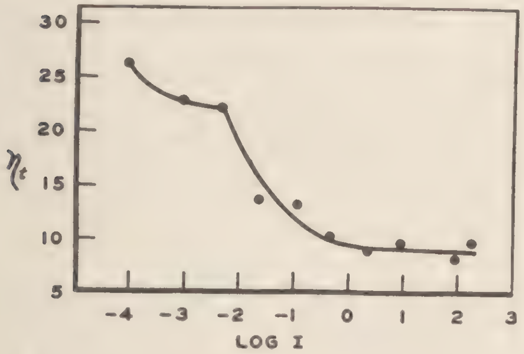

Figure 32. The average error in making stereoscopic range settings as a function of the intensity of the background (22).

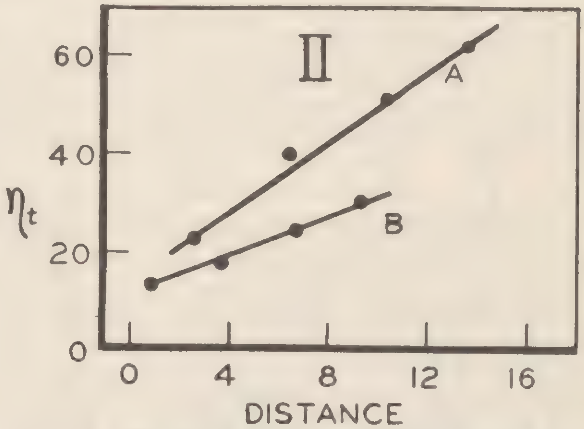

Figure 33. The average error of stereoscopic settings for various separations between target and reference line (6).

increases linearly with increasing distance between target and fiducial line. Curve A is for separations in a horizontal direction. Curve B shows the results for separations in the vertical dimension. The distances on the horizontal axis are in mm. where 2.6 mm. equals one degree of visual angle. The results for the vertical separation have recently been extended to separations down to 20 seconds of visual angle and the results are similar to those in Figure 33. These results are shown as the middle curve in Figure 30, where they may be compared with the results for vernier acuity. It is clear that stereoscopic acuity is much more resistant to the influences of separation than is the case for vernier acuity.

When we introduce different vertical separations between the target and the range reference line in the two eyes, we have what is called a vertical disparity. Recent results show that the average ranging error increases markedly and systematically with the magnitude of this vertical disparity. The extent to which the ranging is affected depends on the target. A target with the edge nearest the fiducial line slanting between 30 and 60 degrees from the vertical is more sensitive to the vertical disparity than a vertically oriented target.

The above results on stereoscopic acuity have direct application to optical range finder operation. The intensity function tells us that ranging will be poorer in dim illuminations than in bright and that any device such as introduction of neutral or colored filters that

reduces the intensity below that required for maximum stereoscopic acuity will increase average ranging error. The separation function of Figures 30 and 33 has direct application because of tracking errors in optical rangefinders. A rangefinder operator coupled to a poor tracking operator or apparatus will have a larger average error than one coupled to a more accurate tracker and the average range error will be directly proportional to the error of the tracker.

The results for real depth discrimination parallel closely those for stereoscopic acuity. Curve B of Figure 29 shows real depth discrimination as a function of the background intensity. For the real depth situation the results on target-fiducial mark separation are similar to those of Figure 33. Again a linear relationship exists and again these observations have recently been extended to separations of 20 seconds of arc.

SOME RESULTS FOR TESTING AND TRAINING

We have seen some of the variables that affect sensory function. Let us now turn to some of the results obtained in testing, selecting and training for these functions.

During World War II several tests were developed to measure what was called "night vision." The general purpose in this testing program seemed to be to devise a test that would measure the capacity of individuals to see at night. Some of these tests, such as the Hecht-Shlaer Adaptometer measured the threshold for seeing a short (one-fifth of a second) flash of light. Others such as the Radium Plaque Adaptometer measured the threshold for detection of a stimulus silhouetted against a background of fixed, and low, intensity. The Radium Plaque Adaptometer (hereafter referred to as the RPA) used a block T figure and the task was to correctly state the orientation of the figure (up, down, right or left).

The test-retest reliabilities of these tests vary from test to test and from one study to another. The test-retest reliability of the RPA, for example, has been reported in the range from 0.43 to 0.82, with perhaps most of the reports falling in the 0.60's. The reported reliability of the Hecht-Shlaer has ranged from 0.42 to 0.64 with values as high as 0.77 if the correlation ratio was used rather than the product-moment correlation. The average reported reliability is lower than that of the RPA. Generally speaking, the reliabilities of most tests developed during the war fell within the range of 0.40 to 0.80. The Army Air Force-Eastman Kodak test and the Rostenberg test show higher average reliabilities than most other tests, but fewer studies involving large populations of subjects have been reported. For example, a reliability as high as 0.94 has been reported for the AAF-Eastman test with the average probability in the 0.80's. But no report of a reliability greater than 0.80 was based on an N greater than 33. For the two studies with test populations of 45 or more one (N = 85) found a reliability of 0.80, the other (N = 200) yielded a reliability of 0.68.

We have attempted to show in discussing the absolute threshold that we should not expect high reliability with a single test measure of performance near threshold. From the point of view of discrimination, threshold is a statistical concept. The probability variations of Figures 1 and 2 are a part of the phenomenon we are studying and the range of this probability function is not small. When we add to the variability of this type the fact that many "night vision" tests employ a forced guess procedure, and when we add the fact that the scores from many of the tests are not normally distributed, it appears that the reliabilities are not lower than could be expected.

Let us consider the problems of test-retest reliability of a representative test, the RPA, in the light of the data we have reviewed in the preceding pages. The frequency of seeing curves of Figure 2 show that a well-trained observer, when tested on two days, saw the stimulus 16 times out of 20 presentations the first day. The second day at the same

intensity the same observer saw the stimulus 7 times out of 20 presentations. This amount of variation is commonplace under the most controlled laboratory testing. These numbers correct may be considered analogous to scores on the RPA test which also uses 20 stimulus presentations. To this source of variance we must add the variance imposed by the forced-guess. There is one chance in four of guessing the orientation of the RPA figure. Therefore, the testee should, on the average, guess 5 out of 20 presentations of the RPA test patch with no contribution from the visual system. But the number correct in a set of 20 will show chance fluctuations such that, for example, one time in ten the guesser should get 2 or fewer correct and one time in ten he should guess 8 or more correctly. These two examples of variability represent respectively, 45 or 30 percent of the total possible test score range. In most tests there are other sources of variability. In many tests, for example, no fixation light is provided. This means that in any particular exposure or trial the probability of seeing will depend on the retinal region stimulated. If scanning for the target is permitted the probability will depend on the scanning procedures of the observer tested. We have seen that the threshold may change by a factor of 50 to 1 with change in the retinal region stimulated.

Obviously, all of these factors will not be involved in all tests, but no test is free of all of them. Nor do all of the variables apply to all individuals. An observer whose threshold range is such that his threshold on all days is higher than the fixed intensity of a given test instrument will not show a day-to-day threshold variance on that test. Similarly, an observer whose threshold range is always below the test intensity used will have no variance in test score attributable to threshold change but will have variations due to his guessing. In view of all of the known sources of variability, some of the reports of reliability are surprisingly high rather than low.

When we turn to the question of the validity of the "night vision" tests we encounter greater difficulties. First we must clearly state for what we desire them to be valid. As a measure of sensitivity after dark adaptation all tests are valid by definition, of course, for performance on tests such as the Hecht-Shlaer is what we mean by sensitivity. If we use them as predictors or measures of performance of visual military tasks involving low levels of illumination, then the question cannot be conclusively answered either on a priori grounds or on empirical grounds. The major difficulty in establishing the validity of "night vision" tests is the difficulty in getting an adequate measure of the military performance. The few studies that have attempted to meet this difficulty have shown low or zero correlations between "night vision" test scores and performance on night duty.

In an attempt to circumvent the difficulties of measuring combat duty performance a number of studies have correlated test scores with scores on various training devices and with so-called field tests. The correlations obtained have varied from -.07 to .83. These studies are difficult to summarize. They have differed in "night vision" tests used, in field or training device used and in methods of scoring both. Some experiments have shown a serious attempt to get a measure of field performance, others have merely made the vision test figures larger and attached them to the outside terrain. The concept of a field test is weakened when one correlates visibility of a Landolt Ring test in the laboratory and the visibility of the same figure attached to trees and shrubbery and illuminated with the night sky.

In evaluation the results of correlations of test scores and field or training measures we find once again a tendency for the highest correlations to be linked with the studies with the smallest N's. The correlation of .83 (the highest reported) was obtained with a group of 16 observers. No studies using more than 50 observers have yielded correlations above .70 and none with an N greater than 100 have given correlations above .60. Very roughly speaking, the correlations distribute themselves uniformly from -.10 to .80 with minor peaks between .60 and .70 and between 0 and .10.

Further analysis of these data is probably not warranted because of the many confound-

ing variables, particularly the differences in "night vision" tests used and the differences in the nature of the training or field test measures taken. Any analysis is likely to reveal the two main features of the data, the diversity of results obtained and the impossibility of drawing general conclusions concerning the agreement between "night vision" test scores and measures of field tests.

In the case of the reliability of "night vision" tests the point was made that high reliability could not be expected with tests that involved a small number of presentations and a short period of time. This conclusion was forced on us by the data on visual function and the nature of the tests used. The basic data on visual excitation can contribute also to our understanding of the relation between any single "night vision" test and a measure of field or combat performance. The first part of the paper was devoted to showing the many variables that influence visual acuity and contrast sensitivity at low levels of illumination. In field or military performance most of these variables will come into operation. Targets will vary in size, contrast, position with respect to the observers' line of sight, etc., and any measure of combat performance will, therefore, be some complicated function of performances under a wide variety of circumstances. Only in the case where performance under one condition is highly correlated with performance under other conditions could we expect a test as restricted as most "night vision" tests to be related to field performance. There is little evidence that such high correlations exist. On the contrary, the evidence points in the direction of low correlations between scores on different tasks at low levels of illumination.

For example, the RPA test involves a single shaped figure, a black T. The task is to report the orientation in one of four positions. The test utilizes only one intensity level and one size of target. Other tests may not have these restrictions but will have others. Some tests measure at one fixed position, i.e., they furnish a fixation point. In considering the restriction in fixation for example, we find that the correlation between maximum visual acuity in the periphery at a low level of illumination and the acuity at any fixed retinal position varies with the retinal position. Figure 34 shows for a group of subjects, the rank order correlation between maximum peripheral acuity and acuity at 0^{o}, 2^{o}, 4^{o}, 6^{o}, 8^{o} and 10^{o} away from central fixation. This function passes through a maximum in the region of maximum visual acuity for the intensity level used and decreases for greater and lesser eccentricity. This means that a score based on performance for many fixation positions is not likely to correlate highly with a test score based on a threshold at one retinal position.

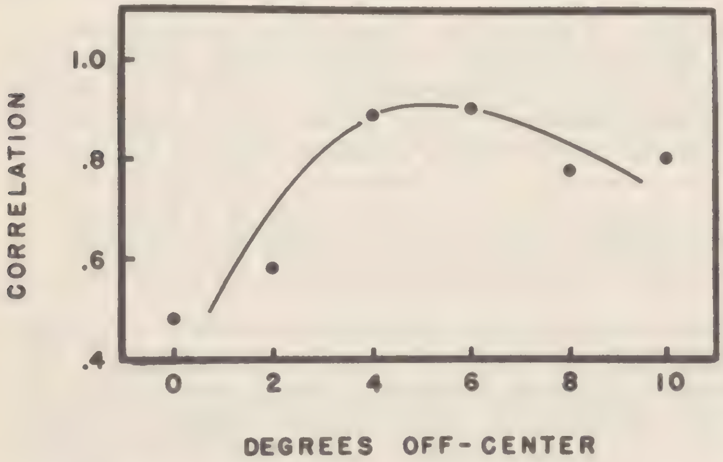

Figure 34. The rank-order correlation between maximum acuity and acuity at various positions in the periphery. The acuity was measured at a low level of illumination. Data from (26).

The results obtained in correlating "night vision" test scores and performance either in military operations or in field or training situations leads us to consider the common assumption that there is a single capacity to see at night. The results indicate that this single factor does not exist, that the performances under different conditions are not highly correlated and that the first step in achieving high validity after the establishment of an adequate criterion, should be testing under more varied conditions. High validity will not thereby be guaranteed, but in the absence of greater scope in testing procedures we are assured of low validity.

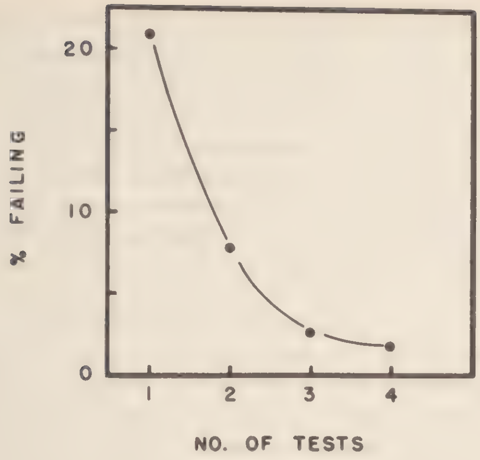

Figure 35. The percentage of individuals failing the R.P.A. test in four successive administrations. Data from (18).

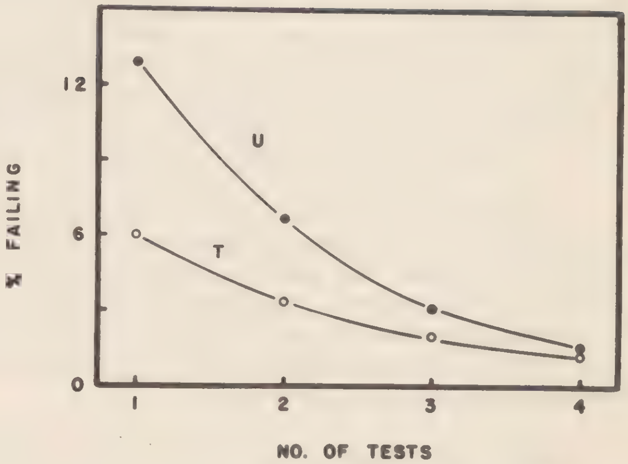

Figure 36. The effect of training on a modified Evelyn Night Vision Trainer on the percentage of individuals failing one, two, three, or four R.P.A. tests. See text for discussion. Data from (25).

There is no doubt that performance on "night vision" tests is affected by training and practice on the tests. The extent to which such practice generalizes to other performances at low illuminations has not been clearly established. Many studies point to the increase in RPA scores, for example, on second and third administrations of the test. The results of one of these studies is shown in Figure 35. This figure shows the percentage of individuals failing the RPA test on four successive test administrations. Scores on the RPA test seem to increase as a result of one period of training on a modified Evelyn night vision trainer, although negative results have been reported. Figure 36 shows the results of one experiment on the effect of night vision training on RPA scores. This figure shows the percentage of cases failing one, two, three, and four administrations of the RPA test for an untrained group and for a group previously trained on a modified Evelyn trainer. In this study only those who failed the first test were given the second, only those failing the first and second were given the third, etc. The percentage value in the figures are based on the number taking the first test. The major effect of training seems to be the change in the percentage failing the first test. Six per cent of the trained group failed the first test, while 12. 9 per cent of the untrained group failed the first test. After the first test approximately one-half of those tested in each group failed each test and this result is mirrored in the convergence of the two curves of Figure 36. These results give some indication of the extent to which practice or training for seeing at low brightness levels generalizes.

There are no conclusive studies on the effect of training procedures on combat performance, although again this is undoubtedly due to the difficulties in measuring adequately combat performance.

Finally, let us consider one other visual function, visual acuity, from the point of view of test design and selection. The most widely used tests of visual acuity are those using either a checkerboard design, block letter design, or the broken circle pattern. Examples of these types of acuity figures are shown in Figure 22. The checkerboard test requires the proper identification of one arm in four that is different from the rest. The letter test requires correct identification of the letter. The Landolt C test requires the correct identification of the quadrant in which the break in the circle appears. Any attempt to average or summarize the many studies during World War II on the test-retest reliability of acuity

tests would probably conclude that the checkerboard test has the highest reliability. Such a conclusion, of course, does not do justice to the data. The reliability of the checkerboard test is usually reported in the .80's, less frequently in the .70's and .90's. If we are interested in the relative merits of test figures alone, some of the superiority of the checkerboard figure may be spurious; until near the end of the War the checkerboard figure was always used in the Ortho-Rater, an apparatus that maximized the probability of constant test conditions, test procedures, and scoring. Support for this interpretation may be found in the fact that, in the hands of some investigators, tests such as the Snellen test characteristically yielded reliabilities comparable to the Ortho-Rater test.

The interpretation of the relative reliabilities for the various acuity targets must also be influenced by the recent work on the visibility letter and numeral designs. Not until World War II was any serious effort made to select letters and style of printing to be used for letter acuity tests. Differences in both the difficulty and the confusability of letters and the dependence of both on the print style has only recently had its effect on test construction. One effect has already been the increased reliability of letter tests, and additional research is required.

Many investigators now prefer the letter tests with the letter designs modified and the letters judiciously selected. This trend seems to be based partly upon the increased reliability when letter selection and design are considered and partly upon a judgment of the visual functions being tested. It is felt that the letter target measures more subtle visual function than is the case for a simple repeating design such as the checkerboard.

The argument on the basis of the reliability is straightforward; the argument on the basis of visual functions tested seems to rest on data that have not yet been rigorously presented. We encounter again the question of the validity of the tests for military selection. We have clear evidence in the case of visual acuity that we are not dealing with a simple visual function. Factor analyses of visual acuity test results clearly show that more than one factor is involved. In fact, in one study for the test battery used, 12 factors were found. This raises the question of the relative importance of each factor for military performance. It is not likely that all factors are equally important for military selection or that the factors important for one type of duty will be the same as the factor (or factors) required for another type of duty.

Once again we do not have adequate data on the basis of which the Armed Forces could choose from among the many acuity tests. In addition to reliability and the factor loadings of each test, we must have data from job analyses of military performance and from validation studies. These indispensible data are lacking at the present time. Everyone agrees that the extreme cases of visual acuity defects should be screened, as should the cases of extreme night blindness. But no one has frontally attacked the question of what constitutes an extreme case for military operations. References are frequently made to estimated requirements in day-to-day civilian activities, in industry, etc., but the relevant information for a decision on military selection is not available.

CONCLUDING REMARKS

It is obvious that the study of vision is not the work of a single science, but depends on the data of many sciences. We have restricted ourselves to a discussion of what the human observer can do on the basis of visual stimuli. Particularly, we have been concerned with some of the limitations placed on him by the visual sensory system. But much more than this must be known before we can predict what the observer will do in a particular combat situation. Some of the additional variables are psychological in nature and lead to such concepts as motivation, emotional stability, etc. Some of these variables will be discussed in other reports submitted to the Committee.

Other variables that will affect the extent to which we can predict the individual's behavior will appear in the data of the physical sciences. We have seen that most of the laws covering visual discrimination are stated in terms of physical or geometrical dimensions of the stimulus at, or near, the observer. When we talk about the contrast sensitivity of the eye, for example, we specify the constrast of a stimulus figure a few feet or yards from the observer, or in many cases, at the eye position. But the stimulus object in case of enemy aircraft or surface ships may be many miles away and the contrast at the point of the observer will depend importantly on the distance involved. Both size and contrast will vary with the distance. To predict the range at which a normal observer will detect an enemy plane, for example, we must know the (1) contrast sensitivity of the eye, (2) the contrast at the target and (3) the contrast rendering properties of the atmosphere. The last of these will be defined in terms of a function relating the contrast at a point, the contrast at the stimulus object, and the distance between the point and the object. One parameter of this function will be a term covering what we normally think of as the visibility or atmospheric conditions. The same kind of information is required for other media, such as ocean water, and for man-made media, such as optical instruments.

Consider the use of binoculars for night vision. We have seen that the probability of detection is a function of the area of the target; for a given target-to-background contrast, the larger the area the greater the probability of seeing. Therefore, the use of binoculars would be expected to increase the probability of seeing a given target. But if we are using the binoculars at low levels of illumination, such as for night lookout, several other variables must be considered. The binoculars will decrease the contrast and the loss in detectability from decreased contrast may more than offset the gain from increased area. We would also have to consider the light loss due to the use of binoculars through reflection. In this case, field tests during World War II clearly showed the advantages of using binoculars designed for night search.

Many other examples could be given to show the extent to which the application of discrimination data depends upon the data of physics and other sciences. These important areas of research have not been considered under the heading of human discrimination, although in many cases they are necessary for the application of the discrimination data.

Finally, we might point to the way in which the use of sensory data depends on the way we conceive of the human engineering problem. A recent example of this is to be found in the influence of information theory on discussions of human performance. A particular conceptual framework of this sort usually suggests or emphasizes certain kinds of experiments and experimental results. For example, viewing human discrimination in the light of information theory, two types of data become important. These are data of the speed of responding and data on discrimination when many categories of response are possible. We can specify the information in terms of the number of alternative responses that can be made, and with the speed of responding, we can state the capacity of the system. In these terms many of the data on span of discrimination, serial reaction time, etc., are emphasized.

SUMMARY AND CONCLUSIONS

From this brief review we have seen that we have many data showing the variables that affect visual function. All of the variables are important in the sense that they all affect the probability that a stimulus will be seen.

The variables that have been discussed may be roughly placed in two classes, (1) those that refer to the characteristics of the stimulus and (2) those that refer to the condition of the observer. Examples of variables that were considered under the first heading are the size of the stimulus, the shape and color of the stimulus, the length of time the stimulus is

exposed, the position of the stimulus with respect to the line of sight, and the brightness of the surrounding visual field. The second class of variables may be subdivided into those conditions of the observer that are relatively permanent and those that are transient. We did not discuss in detail the variables that "permanently" affect the conditions of the observer. Inferentially, this topic entered the discussion in many places. Any treatment of individual differences in thresholds and all questions of selection and training for visual functions are based on the assumption that such stable conditions exist. Examples of variables that affect the condition of the observer over short periods of time were covered in the discussion of light and dark adaptation.

Some of the variables discussed have direct and obvious application to military problems. This is particularly the case, for example, in the work on the visibility of radar signals, where the importance of the intensity of the signal, the brightness of the background, the size of the pip, the length of time the observer is adapted to radar room illumination, all follow from well known visual functions. Similarly, there are direct applications to day and night lookout, where background brightness, level of adaptation, and the size and contrast of the target are important. It is expected that more and more of the variables discussed will have direct application to military operations as it becomes possible to design the task to suit the observer, rather than designing the observer to match the task.

There remain areas where what appear to be visual problems have not been adequately solved. In these cases we generally encounter one of two difficulties: (1) the visual problem is not clearly or adequately stated, or (2) the problem is properly stated but we lack the data for giving the solution. A difficulty of the second type is always easier to overcome. Questions concerning the legibility of figures, the readability of dials, general questions concerning methods of presenting information to the observer all require additional research before definitive solutions can be presented. But in most of these cases the questions to be studied can be stated at the outset. In other cases, e. g. , night lookout performance, it has not yet been established what the visual problem is. This suggests that one of the greatest needs at the present is for research that will show what the demands are on the human observer. Inadequate attention has been given to the specification of the stimulus conditions for the combat situation. More data are needed to bridge the gap between the terms used by the line officer to describe the task and the terms found in a scientific discussion of visual discrimination. To select the relevant information from the research in vision requires a job analysis of combat activities. The point is illustrated by the work in much of the vision testing program where the emphasis on reliability has not been accompanied by an interest in showing that the functions now reliably tested are indeed essential for performance. We know that we can test "night vision" with a reliability of . 70 but we have not yet shown that the test scores correlate with performance on night lookout.

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NIGHT VISION TRAINING:

A SUMMARY OF RESEARCH AND PRACTICE

Brant Clark

INTRODUCTION

Military operations have been carried out at night since the earliest times, both on land and at sea. However, these activities have become both more extensive and elaborate since the beginning of World War II. This development of night actions has been particularly notable in aviation which before World War II was almost completely limited to day operations. The development of electronic devices as aids to detect objects at night or during poor visibility and the development of various navigation aids has played the dominant role in the expansion of these activities. In spite of this "vision beyond sight," there are situations in which the use of such devices is impractical, and it is difficult to develop these indirect cues from instruments to the point where they have the full force of direct vision for the observer. It is important, therefore, that persons, who must work under conditions of highly reduced intensity, have the highest possible visual efficiency in very dim light.

One technique to accomplish this increase in efficiency is to develop a test which will select persons having the highest sensitivity at low levels of illumination, or at least eliminate those having low sensitivity. Many such devices have been developed both for experimental work and for mass testing and have been used on a large scale. But selection even if it is reliable and valid has its limitations since few persons, particularly in urban communities, have had any extensive experience in seeing at really low levels of illumination. Most people do not even know that there is anything to learn about seeing at night. They do not know that seeing at night is different from seeing in the daytime and most of them have a number of clear misconceptions about the process. They regularly express great surprise at the demonstration of the most elementary principles of seeing at night and the fact that a great deal can really be seen. These persons may have very high sensitivity but very poor visual efficiency.

The general objective of night vision training programs is to increase the efficiency of seeing at night and thereby increase the general efficiency of the person doing the seeing. More specifically, the objectives most commonly mentioned are: (a) To give the trainee a body of sound basic information regarding the use of the eyes at night (e. g., how to develop maximum sensitivity; how to protect his eyes at night); (b) to develop actual skill in using the eyes at night (e. g., learning to regognize objects under starlight illumination); (c) to develop adequate attitudes toward seeing at night (e. g., to develop belief that one can see at low levels of illumination and to reduce the fear commonly associated with night operations).

This report has two major parts. In the first part a number of manuals and other discussions of night vision training were analyzed to select the basic principles most commonly emphasized. The literature on scotopic vision was then surveyed to evaluate each principle presented in the light of experimental evidence. No attempt has been made to make an exhaustive analysis of the literature; however, an attempt was made to select representative studies in the evaluation. Much excellent work has been reported in military research reports but only a very limited number of these are cited. Of course, many of these basic principles have been widely known for many years and are summarized in Helmholtz's Physiological Optics (45). Recent summaries of research which are particularly pertinent have been made by Bartley (8, 9), Graham (18) and Judd (30). The second part of the report consists of a brief description of several procedures which have been used in Night Vision Training in this country, in Canada, and in England. An evaluation of these procedures in the light of the objectives and research is given.

BASIC PRINCIPLES IN NIGHT VISION TRAINING

The most universally used techniques used in Night Vision Training involve teaching certain basic principles of seeing at night under starlight conditions. The principles listed here have been selected chiefly on the basis of the frequency of occurrence in manuals and lectures available (2-7, 10, 11). It is believed that this selection gives a fairly complete and representative statement of the principles emphasized in Night Vision Training programs. The statement of the principle in each case is the author's and is usually an attempt to generalize from several sources. The principles are grouped in arbitrary categories which are not related to any systematic presentation of the material in a training program.

A. Basic anatomy and physiology of rod vision. All training schedules give some statement regarding the anatomy and physiology of rod vision although it is usually perfunctory in nature and limited to the most elementary facts.

1. There are separate mechanisms for vision in daylight and for vision at night and each has its separate functions. This statement is based on the anatomy of the retina which is well known. The separate functions of the rods for low intensity and cones for high intensity have been described by many investigators (8, 9). The distribution of rods and cones has been studied in detail by Østerberg (40). He has described the concentration of cones alone in the fovea and their rapid decrease as the distance from the fovea increases; he showed also that the rods increase in number from the fovea peripherally to approximately 15-20 degrees and then decrease.

2. Rod vision is dependent upon a photochemical process in the retina. The photochemical processes involved in rod vision were hypothesized for many years before their actual presence was demonstrated, but the chemistry of the process is now fairly well understood. Wald (47) has recently summarized the chemistry of rod vision in terms of the known reactions. Much of the physiology of the retina reflects the cycle of reactions involving light, rhodopsin, vitamin A + protein and retinene + protein.

3. The rods are sensitive to extremely small amounts of radiant energy. The amount of radiant energy necessary at the stimulus threshold is extremely small. Helmholtz (45) cites work by Eyster in the 19th century indicating that the amount of radiant energy under optimal conditions varied between $1.3 - 2.6 \times 10^{-10}$ ergs. Hecht et al. (26) in more carefully controlled work found that "the minimum energy required for threshold vision under optimal physiological conditions yield values between 2.1 and 5.7×10^{-10} ergs at the cornea, which correspond to between 54 and 148 quanta of blue-green light." When losses through the optical mechanism are taken into account the threshold value absorbed by the retinal rods is reduced to 5 to 14 quanta.

B. Factors involved in the development and maintenance of dark adaptation. The first systematic investigation of dark adaptation was made by Aubert (45) who also suggested the term adaptation. Aubert studied the course of adaptation by measurements of the amount of current flowing through a platinum wire which glowed in the dark. Very precise adaptometers are now available to trace the course of adaptation for either the rods or the cones so that precise measures of the effects of various variables on the course of adaptation can be accurately determined. The principles involved make up the major portion of discussions of night vision. The most significant ones are:

1. The eye is adaptable to a wide range of intensities of light. The actual range of intensities quoted varies considerably. However, there is ample experimental evidence of a great range as shown by the use of logarithmic units to express it. Bartley (9) expresses the ratio of intensities from the stimulus threshold to the upper limit of visual tolerance to be 1 to 10 billion or a range of approximately 100 decibels. Bartley's range is based on a low rod threshold after 10-12 hours in darkness of 0.000001 millilambert and 16 lamberts as the upper limit of tolerance.

2. Adaptation depends to some extent on the change in the size of the pupil but chiefly on the increase in sensitivity of the rods. The pupil normally increases in size during exposure to darkness to a maximum of some five times its normal diameter. This permits approximately 25 times as much light to enter the eye. This could account for only a small fraction of the increases in sensitivity summarized by Bartley (8, 9). Studies of the chemistry of the retina make it clear that dark adaptation is closely related to these processes (46-48). Neurological factors are also involved (9).

3. Thirty minutes in complete darkness are required to dark adapt the eyes. This period of time is suggested almost universally as the minimum time necessary to dark adapt the eyes. Although the rate of dark adaptation varies widely for different situations (vide infra), there is much experimental evidence to support 30 minutes as a practical minimum period under average situations. It should be pointed out, however, that adaptation proceeds long beyond this point. Many studies of cone adaptation indicate that the major drop in a cone threshold takes place within ten minutes (8, 9). Similarly, many studies of rod adaptation demonstrate that the adaptation curve exhibits only a small decrease after 30 minutes. However, measurable drops in threshold occur beyond 30 minutes. This is particularly true if, for example, the eye is pre-exposed to very bright light (9, 14, 23).

4. Red goggles or red light may be used to achieve adequate dark adaptation and to protect adaptation once achieved. This procedure has been widely used in practice in many different situations. The procedure most commonly suggested involves wearing red goggles 20 minutes in moderate illumination and then remaining in darkness 10 additional minutes. Miles (38) suggested the use of a 590 mμ cut-off goggle. The specifications for the red filter called for 1% transmission between 590 and 600 mμ and zero transmission below 600 mμ. Filters with a cut-off at about 620 mμ have also been used (9). The adaptation value of the filters is based upon the difference in the luminosity curves for the rods and cones. With transmission beyond 600 mμ being of the order of 1%, the rods are stimulated by only 1% of the total flux to which they are sensitive whereas the cones are stimulated by approximately 10%. The filter passes enough light to permit cone vision sufficient to do a variety of tasks. Therefore, if the glasses are worn for 20 minutes and the observer remains in the dark 10 additional minutes, the rods will in effect be in the dark 30 minutes and the cones 10 minutes. This achieves a practical level of adaptation as described above. The protective value of red light and red goggles can be understood on the same bases.

The value of these filters in the development and protection of dark adaptation has been demonstrated in several studies (e. g., 15, 27). It has also been shown that the protective value of orange goggles which transmit a greater portion of the spectrum and higher intensities is much less than for red goggles (15). It is clear that these red filters have value only as devices to make the adaptation period less boring or to protect the eye. Using them to some small degree delays the adaptation process. The efficiency of vision is necessarily reduced while the filters are being worn. This is particularly true of color discrimination since the major part of the visual spectrum is not transmitted by the glasses. Vision at low levels may be completely eliminated by them since they transmit only a small fraction of the incident light.

5. When white light must be used for seeing, minimum interference with adaptation is produced by brief exposures of the lowest intensity possible. Any white light tends to reduce the level of dark adaptation. The interference is a function of wavelength, intensity and duration (9, 27, 48). Some instrument panels have been made using red light of low intensity to reduce the effects of the exposure when it is necessary to read the instruments.

6. Brief exposures to bright light such as produced by searchlight, and flashes of

various types reduce visual effeciency, but recovery is more rapid than normal adaptation. Specific data supporting this statement have been found in two investigations (1, 23). Additional studies are described by Bartley (8, 9).

7. An effective method to protect adaptation is to cover one eye when seeing is necessary. Helmholtz (45) reported the independence of adaptation in the two eyes. This is supported by recent studies demonstrating the importance of the retinal chemistry in adaptation (47, 48).

8. Individuals who are to make night observations should avoid brilliant sunlight during the day or wear low transmission glasses. The effect of pre-exposure to very brilliant light in elevating the stimulus threshold, delaying adaptation and other ocular changes is well known (8, 9, 23, 31). It has been shown in several studies (14, 23) that the higher thresholds may last for 24 hours or more. The protective value of wearing high density filters has also been demonstrated (14). They indicate that the transmission of such filters should be 15% or less for effective protection against brilliant sunlight and 5% when exposed to highly reflecting material such as white sandy beaches.

9. Constant practice is necessary to maintain a high level of skill at scotopic levels. This is a statement which is commonly made but there is little supporting experimental evidence. A British paper (4) reports the maximum efficiency being obtained in three days of practice. Low (33) reports that 25 hours of practice are necessary to bring peripheral acuity to near maximum efficiency. No studies of the permanence of improvement in actual skill in seeing are known to the writer. Such data would be valuable for the evaluation of Night Visual Training programs.

10. Good physical condition is necessary for superior scotopic vision. A number of factors related to physcial condition have been studied. Vitamin A is one of the basic substances in the chemistry of the rods (47) and several studies have shown that deficiency in vitamin A will reduce scotopic sensitivity (25, 29). Some studies have shown that night blindness will sometimes show recovery to normal on a return to normal vitamin A, and sometimes it will not (29). Anoxia also produces marked reduction in brightness discrimination (9, 24). Deterioration begins at fairly low altitudes, becomes obvious at 8,000 feet and marked at 15,000 feet. Rod and cone vision are equally affected as a result of impairment of the functioning of the visual pathway rather than the photochemical process.

11. The rate of dark adaptation can be increased and the threshold lowered by extra-visual stimulation. Although this "principle" has not been widely expressed in Night Vision Training programs, it has been expressed in many other places. Chapanis and his co-workers (12) quote one investigator as follows: "It can be seen, therefore, that excitation of any receptor produces changes in the sensitivity of the dark adapted eye." These workers tested this hypothesis in a carefully controlled experimental situation using six subjects with the Hecht-Shlaer adaptometer as a measure of adaption. They used odors, sounds and light physical exercise as the stimulating mechanisms. Comparisons were made with control runs. They report, "The results of all experiments are completely negative. None of the stimuli used in this experiment either facilitated or inhibited dark adaptation, contrast sensitivity or form discrimination at low illuminations." It is difficult to see how such stimulation could influence the retinal chemistry which is the dominant factor in adaptation (47).

C. Limitations of vision at night. The sensitivity of the rods to very low amounts of energy has already been described. Numerous studies have also been made of the limits of discrimination during scotopic vision and one indicates a greater night accident rate as the night illumination decreases (41). All Night Vision Training outlines make a point of stressing the limitations of scotopic vision as well as its extreme sensitivity. The principles most frequently stressed are:

1. Color perception is impossible at scotopic levels of intensity. One of the most widely known facts concerning scotopic vision is that although sensitivity is high over a fairly wide spectral range, discrimination of color is absent. Helmholtz (45) describes the scotopic condition as follows: "The eye is totally colour blind, as can be verified without difficulty. As soon as it is possible to distinguish colour, it is a sure sign that the intensity is already above the threshold of the fovea centralis." This has been verified by many other experimenters (8, 9).

2. The apparent brightness of colored objects in photopic vision is different than in scotopic vision. This is a general statement of the shift in visibility curve which is dependent upon the difference in sensitivity of the rods and cones for various parts of the visible spectrum. Reds appear relatively less bright and blues relatively brighter under scotopic intensities (8, 9).

3. The visual acuity at scotopic levels is far below the acuity at photopic levels. Studies have been made using various types of targets to measure the visual acuity (8, 9). Experiments by Low (33, 34) confirm earlier work showing that the acuity at scotopic levels roughly approximates that found at photopic levels for peripheral vision. Rowland and Rowland (43) have found that the greatest scotopic sensitivity for form is to be found between 4^{o} and 12^{o} from the fovea. This is to be compared with the greatest sensitivity to light which is to be found 5^{o} - 10^{o} farther into the periphery.

4. It is possible to construct tables of distances at which objects can be observed at night. Tables of the distance at which objects can be observed at night have been prepared and have been widely quoted (3, 4). It is not known whether these are derived from theoretical or empirical data; however, Chapanis (11) makes a brief reference to comparisons between laboratory observations and those in the air citing a British source.

5. Depth perception is impaired at night. The classical cues for depth perception have been resummarized recently by Graham (18). All of these cues both monocular and binocular, are reduced in effectiveness by severe reduction in the intensity of light. However, no experimental data on this point to determine the exact limitations of scotopic depth perception are known to the author.

6. After effects of exposure to bright light may produce illusory effects. Negative after-images are a fundamental visual effect (9, 30) and the dark adapted eye is particularly susceptible to them. They may persist for considerable periods of time. When inadequate framework is present in dim light, the observer may readily mistake the after-image for a real object and it may appear to move and change distance. Seeing objects in the dark in this fashion was described in 1634 and at that time became a favorite magician's trick (45).

7. Night vision shows periodic fluctuations in sensitivity. Low has recently studied this effect in 43 normal subjects and finds that it is pronounced and annoying in making threshold measurements (33). Observations may show these fluctuations at or near threshold levels as a result of adaptation (8, 30), fluctuation of attention (18) or the variations in the stimulus itself where only a few quanta of energy are involved (26).

D. Recommended techniques for optimum seeing at scotopic intensities. Assuming that adequate adaptation has occurred and that protective measures have been used, there still remains the problem of using the eyes to the maximum efficiency. The procedures for optimum seeing differ radically from seeing at photopic levels. The procedures are:

1. Use off-center vision in seeing at very low intensity levels. The basic facts supporting this are based upon the lower sensitivity of the rods and the location of a rod free area and night blind spot in the fovea (8, 9). However, the greater sensitivity of

the rods varies with the spectral quality of the light (46). At approximately 500 millimicrons and below the rods are over two log units more sensitive than the cones. However, for longer wavelengths the difference decreases sharply until about 650 millimicrons the sensitivity is about the same; above this point the cones show slight superiority.

2. The most sensitive area of the retina varies from person to person. This has been studied by Rowland & Rowland (43). They report wide individual differences in the location of the most sensitive area on the retina. Their data indicate that the area of greatest sensitivity for form is between 4^{o} and 12^{o} from the fovea. The sensitivity to flashes of light parallels more closely the rod distribution curve reported by Østerberg (40).

3. A systematic scanning pattern is essential to adequate observation at night. This procedure can be supported on purely logical grounds. Such a procedure is obviously necessary to adequately cover the visual field. It is also a good procedure since it causes the field to pass across the retina and reduces the effect of the fluctuation process (18, 30, 33). However, it will not reduce fluctuations at the threshold which are due to variations in the energy itself (26).

4. Regular rest periods are important in seeing at night. This appears to be a reasonable assumption and has indirect support from studies reported by Low (33) and Judd (30). However, no experimental data are known to the writer which bear directly on this problem.

5. It is important to know how things look at night in order to increase the efficiency of night vision. This statement is supported by many experiments not only in the field of visual perception but in other sense fields as well: The organism makes major contributions to its perceptions. An observer's responses are determined not only by stimuli present in his visual field, but by the observer's past history of stimulation, set and the like. Excellent summaries of such studies of visual perception have been reported recently by Graham (18) and by Hilgard (28).

6. The use of adequate night binoculars improves the efficiency of seeing at night. Hecht et al (22) have clearly demonstrated that when binoculars may be used at night they increase the efficiency of night seeing. The improvement is fundamentally a result of the increase in the apparent size of objects. In actual use a compromise is usually necessary between magnification and field size. There is a loss of approximately 50% in transmission through binoculars. Blooming which reduces this effect is therefore important. Proper focusing is particularly important when binoculars are used at night (49). Peripheral vision must be used with the binoculars as it is without them. Visibility through binoculars is greatly reduced by haze or moisture on the lenses.

E. Physical factors affecting visibility. The physical factors involved in visibility at night are essentially the same as those at photopic levels. Those factors most commonly mentioned are:

1. The brightness of an object depends upon the incident light and the reflectivity of the object. This is a fundamental fact of the physics of light (5, 8, 9).

2. Contrast of objects with the background influences visibility. This is another primary factor in visibility which is supported by many studies (5, 8, 9).

3. Shadows are important in visibility at night. Shadows may change the apparent shape and brightness of objects (5, 18). The direction of a light source like the moon

and the position of the observer may change the appearance of objects completely. For example, a plowed field with furrows running across the field of view and the moon behind the observer appears bright, whereas if the observer is looking foward the shadow of each furrow will make the field appear dark.

4. When observations are made through glass, it is vital that it be clean. A British manual (2) cites a study by Craik which found visibility loss up to 67 per cent associated with dirty, scratched plexiglass. The loss was found to depend upon the angle of vision through the glass.

F. Some special problems in visual perception which occur during scotopic intensities. Reduction in illumination reduces the visibility of objects themselves and equally important, it reduces or eliminates the visual framework in which the objects are perceived. This reduces the accuracy of localization of the object in space and contributes to a variety of illusory responses on the part of the observer. Illusory responses can be expected to occur in normal persons whenever the visual framework is reduced. These effects are cited in Night Vision Training programs as follows:

1. Stationary lights may appear to move in the dark. This effect, which has been called autokinesis, has been observed for many years and was probably first noted by astronomers observing the stars. A detailed study of autokinesis was made by Graybiel and Clark (19) with particular reference to aviation. They showed that it occurred uniformly in normal people; that the motion occurred a large per cent of the time, and that it was difficult to eliminate it completely when conditions were optimum for its occurrence. Interruption of fixation and use of a fixed reference object as a sighting device tend to reduce the effect. Similar effects may be observed in other sense fields

2. Visual illusions may occur in flight at night. Autokinesis has been shown to occur in the air at night (19) and flyers are also subject to certain other illusory effects which result from the angular and radial accelerations occurring during normal flight. Two effects are involved, the oculogyral illusion and the oculogravic illusion, both of which produce illusory motion and displacement of visual targets in the dark as a result of vestibular stimulation (16, 17). These effects have been studied in the laboratory and in the air (e. g., 17, 20, 21). The oculogyral illusion which results from stimulation by angular acceleration may produce illusory motion of visual targets which lasts for a minute or more and the illusory effect may be strong enough so that an object moving physically in one direction may appear to be moving in the opposite direction (20). The oculogravic illusion results from stimulation by radial acceleration and involves displacements of visually perceived targets for prolonged periods in flight or on a human centrifuge (16, 17). A recent comprehensive summary of vestibular functions including visual effects has been made by Wendt (51).

3. Illusions of rotation and tilting may occur in the air at night. After effects of rotation which result in illusory perceptions of turning are well known (51). These may occur with visual cues present but are particularly pronounced at night when visual cues are reduced or absent. MacCorquodale (36) has reported prolonged illusions of tilting and turning which occur during flight under simulated night conditions.

NIGHT VISION TRAINING METHODS

A complete description of the many Night Vision Training methods which have been used in the United States and abroad would be almost an endless task. Specific methods have been limited only by the ingenuity of the individuals responsible for the program and the facilities at hand. Their major purpose has been to familiarize the trainees with the fundamental principles of efficient seeing at night. Some have also attempted to develop

specific perceptual skills while all of them, at least indirectly, have been concerned with the reduction of fear of night operations and the development of more appropriate attitudes toward activities which must be carried on at night. This section will include a brief description of typical methods which have been used fairly extensively in Night Vision Training and which illustrate a variety of specific techniques which have been developed. Only a cursory description will be given in each case, but where possible, references will be cited which give detailed descriptions of the devices and methods used.

A. Description of Night Vision Training Methods.

1. Projection trainers. The most commonly used techniques have used some sort of a projecting device which illuminates a screen at various scotopic intensities. Objects are produced on the screens as shadows by means of silhouettes within the device or by means of slides. There is considerable variation in the detail of construction but in general either fixed or movable objects appeared on the large screen at the front of the classroom seating 12-20 students. Cloud formations, glare, and certain other effects can also be produced while slides of ships and aircraft can be projected on the screen for recognition training. The devices require a completely blacked out room and are used to demonstrate most of the principles listed above in connection with a discussion by an instructor. The most widely used projector was developed by Dr. K. A. Evelyn at the Royal Canadian Air Force Biophysics Laboratory at McGill University (3). Modifications have been used by the U. S. Air Force (7) and the U. S. Navy (6).

The Lamplough trainer developed by the RAF used this general principle with a reflector sight. The device made it possible to graph the observer's accuracy in following a moving target so that both recognition and pursuit of an object could be determined. Silhouettes have also been used at the U. S. Navy Submarine School. Here ship models are silhouetted against a dimly lighted background making a "seascape," and training in the basic principles of seeing at night and practice in recognition is possible. The same principle has been used elsewhere using models of aircraft.

2. Model Landscapes. Scale models of real or imaginary land areas were also developed by the RCAF (3) and have been widely used by the U. S. Navy (6). The model is placed on the floor and observed by the trainee from an elevated platform to simulate a particular altitude of observation. The model is illuminated from above at scotopic levels and by "moons" placed in various directions and at different elevations. The model demonstrates the appearance of various types of objects (e. g., water, roads, buildings, beaches, trees, searchlights, shadows) in connection with a discussion by the instructor and comments by the trainees. This is used as supplementary to the projection device.

3. Physical activity under scotopic illumination. This technique was originally developed by the RAF, but has been used to a limited degree in the United States. A room is completely blacked out and illuminated at scotopic intensities. The trainees are dark adapted and put through a series of games designed to develop skill in seeing but the development of morale and appropriate attitudes toward seeing at night are particularly emphasized. Some specific games used in this training are: squash; walking and later running an obstacle course; stick fencing; hockey; shooting clay pigeons; and passing balls. The procedures have been strongly recommended by those who used them.

4. Training by controlled practice on a perimeter. This technique has not been used by the military services but has been developed on an experimental basis by Low (32-34). The training was done using a specially designed 25 cm. perimeter. The subjects worked in pairs under the supervision of an instructor alternating between operating the device and being trained by their partners in a laboratory situation. Thirteen Landolt

rings having breaks varying in size from 0.5 to 10 mm were presented to the subjects and they were required to identify the position of the break in the ring during a brief exposure. Low reports substantial improvement in peripheral acuity and transfer to situations outside of the laboratory and night visual acuity but no practice effects for motion acuity (35). He also believes that his data show that the total process of dark adaptation does not end when the maximum sensitivity to light has been reached.

5. Films and film strips. Films have been widely used as part of night vision training programs to teach basic principles of Night Vision. These devices are limited to a didactic presentation of the material and do not demonstrate seeing at scotopic levels. Illustrations of such films are:

(a) Presenting: Demon Dazzle in Night Vision. Film strip and lecture prepared by Department of Ophthalmology, AAF School of Aviation Medicine, Randolph Field, Texas.

(b) Night Vision for Airmen - Navy Training Film, concerned with Night Flying.

(c) Lookout Training - Night Lookouts - Navy Training film. Concerned with seeing aboard ship at night.

B. Evaluation of Night Vision Training Procedures.

The development of any adequate training program involves the solution of both administrative and psychological problems. Three of the most basic questions which must be answered are: (1) What should be the objectives of the training program? (2) Do the methods used achieve these objectives? (3) How long should the training program continue? In the final analysis this can be summarized for Night Vision Training in the following question: Does the training program produce changes in the trainee's behavior which improve the efficiency of the tasks he must perform at night?

In determining the objectives of the Night Vision Training program it would be desirable at the outset to obtain an exact description of the tasks to be performed and the skills to be learned. It would be important to know what illumination levels are to be encountered in the night operations and the types of observations to be made. No such detailed analyses have been made to the knowledge of the writer although some data are available (3, 5, 37). One is left then with objectives based on competent judgments as the objectives which have been cited above, i.e., teaching of basic principles, skills in seeing and the development of proper attitudes. However, these have always been defined in the most general terms particularly the latter two.

Systematic studies to determine the effectiveness of the Night Vision Training procedures are rare indeed although a few studies may be cited which give results which should be considered to be tentative in nature. Practically all of the principles cited above which are commonly taught certainly have adequate experimental bases. A test of the retention of the material has been found in only one limited study which has been made of the effectiveness of the projector and landscape techniques in teaching these principles. Naval aviation cadets were found to have numerous misconceptions regarding night vision before training. These tended to disappear after training and the cadets appeared to retain the material presented as long as three months after the training periods (13).

Marked improvement in actual skill in seeing following perimetric training has been reported by Low (32-34). He describes very great improvement in visual efficiency of trainees working in pairs in a laboratory and states that this transfers to practical situations including seeing at night. Whether this is adaptable to the training of large groups

and whether there is transfer to specific military operations cannot be determined from his data. A study by Ross and Mueller (42) reported that the per cent of failure on the Radium Plaque Adaptometer test of scotopic vision was reduced following Night Vision Training using the U. S. Navy procedure. Orlansky and Dana (39) also found similar trends, but none of their differences were statistically significant. These two studies cannot be considered to be conclusive since the method of measurement is gross and at only one intensity level (approx. 3.9 $\mu\mu$ lamberts), but they are suggestive.

Only one study of the change in attitude resulting from Night Vision Training has been found. Walker (50) studied 676 Naval Aviation cadets at four stages of training using a questionnaire technique. Little or no change was found to result in the attitude toward the hazard of night flying but 64% of the cadets believed that the Night Vision Training increased their ability to do a good job.

The duration of training schedules has been determined largely on arbitrary bases. No controlled studies have been made to determine the optimum period. Low (35) suggests 25 hours as the minimum training period and another informal statement indicates that three days of training are adequate (2).

The validity of any training procedure can never be taken for granted, but must be established on empirical grounds. Hence the validity of the Night Vision Training procedures can only be evaluated in limited terms since adequate studies of them are not available. On the basis of the data at hand, practically all of the principles taught certainly have adequate experimental basis. Limited evidence is available that trainees retain these facts learned during these sessions. The data on the development of visual skills and proper attitudes using group procedures are too meager to permit an evaluation on this basis. However, Low's studies with individual training are very suggestive of positive results.

The foregoing discussion indicates the need of information in four specific areas for the improvement of Night Vision Training:

1. A job analysis of the visual tasks required in a variety of night operations.

2. The development of valid tests for and methods to increase actual skill in visual perception (as opposed to increased sensitivity) at low levels of illumination.

3. The effect of Night Vision Training on emotional reactions and attitudes toward night operations.

4. The optimum time necessary for formal training programs.

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VISUAL ACUITY AND MUSCLE BALANCE

Richard G. Scobee

Human visual requirements are served by the binocular mechanism. It has been estimated that 85 per cent of all sensations from the world in which we live enter the body via the visual mechanism. If an individual is to orient himself properly in the world in which he lives, his binocular mechanism must be intact.

Attempts have been made to evaluate the visual mechanism for many years. Of necessity, such attempts have almost without exception been largely subjective. An individual must respond to some visual stimulus and describe what he sees, how he sees it, or when he sees it before any analysis of the level of efficiency of the binocular mechanism can be made. There are obvious drawbacks to any analysis based largely upon subjective responses. It is an admission of the defects in the subjective analytical method that a comparatively large battery of tests of the functions of the visual mechanism has been devised. No one test, by itself, can be assumed to give a definite and positive answer about the status of the visual mechanism. Many of the tests which are used have obvious areas of overlap and duplication and yet it is seldom that any two tests measure exactly the same aspect of the visual mechanism.

The ideal would be to study the visual mechanism from the standpoint of several basic functions, devise some specific test for each of the functions defined, set "normal" limits for each, and thus arrive at some adequate analysis of what constitutes the "normal" individual. It has been pointed out that this is not possible.

The several aspects of the visual mechanism which are commonly tested are visual acuity, muscle balance, color vision, and depth perception. Other functions which are perhaps evaluated less frequently but are still important include refractive error -- that is, whether an individual is far-sighted, near-sighted, has astigmatism, or some combination of the three; heterophoria and other various aspects of muscle balance, particularly fusion amplitudes; the range and near point of accommodation, and the near point of convergence. The goal of the military scientist, at least, in studying each of these functions is an attempt to arrive at a definition of what might be considered a "normal" individual. A number of these functions obviously overlap. It might seem a waste of time to apply a large and exhaustive battery of tests to every individual who is to be considered for the military service. The clinician, on the other hand, when confronted with a patient having some subjective complaint is frequently forced to apply an exhaustive battery of tests before a cause for the complaint can be identified with any degree of accuracy and proper therapy instituted. This means that the clinician confronted by a patient with symptoms is far more likely to administer an exhaustive battery of tests than will the military scientist engaged in his never-ending and exhaustive search for the ideal "normal" individual who seldom exists in fact.

There are almost as many types of tests for various aspects of the function of the visual mechanism as there are investigators who have studied the problem. Nearly all of the tests for any one function are similar and yet they are not identical. It is seldom that scores of the same individual on any two tests purportedly of the same function are identical and often correlation coefficients are surprisingly low. This cannot be interpreted as meaning that one test is good and the other is bad because there is as yet no criterion. No yardstick is available which is universally agreed to be without error or fault. The decision as to what might be considered the "normal" individual is probably best made following a study of a large random sample of the population. When proper random sampling techniques are applied, when testing is properly standardized, and when a sufficiently large series of individuals have been examined, then a study of the distribution curves for a large sample of the population may give some indication of the average. An arbitrary decision

may be made as to how much variation from the mean may be allowed in the so-called normal individual. This means that certain pass-fail limits must be chosen and, at least from the standpoint of the military clinician, adhered to in a strict manner in the selection of the "normal" individual.

A certain amount of variation is encountered in the testing of the visual mechanism just as is encountered in the testing of any biological function. This is known as physiological variation and it cannot be completely controlled. In the very recent past, increasing recognition has been made of psychological effects -- that is, the effect of various psychological states on the functioning of the visual mechanism and some attempt is therefore being made to control the psychological state of the individual during testing. Obviously one cannot control the thoughts of the subject being tested and if the thoughts of the examinee wander from one thing to another, it is entirely possible that an outwardly placid individual may in fact be emotionally in a seething turmoil and have his scores on tests of the visual mechanism affected accordingly. It is because of this individual variation that tests of reliability are necessary in the appraisal of any particular test which is to be applied to the visual mechanism. The reliability of a test of the visual mechanism is an indication of its repeatability from day to day and from week to week. A test that is highly reliable should give the same score for the same individual yesterday, today, and tomorrow. Since practically all tests of the visual mechanism overlap and since no two tests are identical, then it is not particularly important to know all details of variation about all tests but simply to know as much as possible, in the light of present knowledge, about a few tests. Thus one selects a battery of tests and proceeds to study each component exhaustively in an attempt to determine what factors will produce variations in the scores on each part. It is only through such studies that the reliability of any one test can be determined and thus scores chosen which indicate the probable "normal" response on the particular test in question. In considering the various functions of the visual mechanism, we shall divide them into four major groups; (1) visual acuity, (2) muscle balance, (3) color vision, and (4) depth perception. If an individual is to be considered normal with respect to his visual mechanism, one must have at least some knowledge of each of these four major functions of the visual mechanism. Only visual acuity and muscle balance will be considered in this report.

REFRACTIVE ERROR AND VISUAL ACUITY

Refractive error may be defined as a physical aberration in the human eye which prevents the perfect imaging of objects located at infinity upon the retina without the benefit of accommodation. The eye which has no refractive error is said to be <u>emmetropic</u> while the <u>ametropic eye</u> is one which does have certain aberrations from the ideal condition of emmetropia.

These physical aberrations resulting in ametropia may be divided into three general categories: (1) <u>axial</u> -- in which the antero-posterior axis of the eyeball is slightly longer or slightly shorter than it should be for perfect imaging of objects upon the retina; the majority of far-sightedness (hypermetropia) and near-sightedness (myopia) is axial. (2) <u>index</u> -- in which the index of refraction of one or more of the component parts of the optical system of the human eye is greater or less than it should be; index ametropia occurs mostly with disease and in senescence. (3) <u>curvature</u> -- in which the curvature of one or more parts of the optical system, the lens or cornea, is greater or less than it should be; curvature ametropia is largely responsible for astigmatism, particularly aberrations in corneal curvature, and otherwise is found only following injury or during disease.

In astigmatism, there are differences in radius of curvature between the principal meridians of the various refracting surfaces in a majority of instances. Astigmatism can also result from unequal changes in the index of refraction of various portions of the optical media but this is relatively uncommon except in senescence or disease.

Refractive errors may be classed as follows:

1. Hypermetropia -- usually axial.
2. Myopia -- usually axial.
3. Hypermetropic astigmatism -- usually curvature.
4. Myopia astigmatism -- usually curvature.
5. Compound hypermetropic astigmatism -- usually a combination of axial and curvature.
6. Compound myopic astigmatism -- usually a combination of axial and curvature.
7. Mixed astigmatism -- usually a combination of axial and curvature, probably mostly the latter.

Astigmatism literally means the absence of a point focus. In measuring astigmatism, the difference in refractive power of the two principal meridians of the optical system is measured and the axis of the meridian showing the greatest aberration is noted in degrees. Thus astigmatism in two individuals may not only vary in amount but in axis and becomes exceedingly difficult to compare because of the almost unlimited number of possible combinations of axis and amount. This difficulty can be circumvented to a certain extent by utilization of the concept of the spherical equivalent.

By using the spherical equivalent, measurements of either simple or compound astigmatism may be reduced to roughly equivalent amounts of hypermetropia or myopia as the case may be. Such a reduction permits comparisons between refractive errors of individuals and studies of large population samples that would not otherwise be possible. The spherical equivalent is more than a mere geometric mathematic concept for it has a practical clinical application, and is thus of value not only in theory but in fact. It is beyond the scope of this paper to discuss the spherical equivalent any further. All refractive data which follow are in spherical equivalents.

The eye of the newborn infant is small. Generally speaking, a small eye is hypermetropic and most infants therefore have axial hypermetropia. As the infant grows, the eyes grow. The eyeball lengthens as it becomes larger and axial hypermetropia decreases. If growth of the eye proceeds past the ideal size (of emmetropia), the eyeball may become too long, relatively speaking, and near-sightedness or myopia is the result. All of the changes occurring during growth of the human eye are not axial -- that is, changes merely in length. Some are index changes and, since growth is rarely symmetrical, many others are changes in curvature of the various refracting surfaces, particularly the cornea. With these remarks in mind, one may now turn to a consideration of the refractive changes occurring in the average human eye from cradle to grave. All of the subjects in the studies to be cited were living in the United States, a majority having been born there.

There are a number of studies of the refractive changes in the human eye during the life span but the most recent and one of the best and most complete is that of Slataper (11).

At birth, the eye of the average infant is hypermetropic to the extent of 2.32 diopters. During the first seven years of life, there is an average increase in hypermetropia of 1.62 diopters or 0.23 diopters per year. This increase is both index and curvature and the average child of seven is hypermetropic to the extent of 3.94 diopters.

Between the ages of 8 and 30, the eyeball seems to lengthen (axial changes) and there is an average reduction in hypermetropia of 3.33 diopters over this period, about 0.15 diopter per year. The average individual at age 30 is thus hypermetropic only to the extent of 0.61 diopter -- very close to emmetropia.

Between the ages of 31 and 64, there is presumably little change in the eyeball either

in length (axial) or in curvature. Nevertheless, hypermetropic changes which are probably index occur to the extent of 1.36 diopters, or 0.04 diopter per year. The index changes may be presumed to be due to the wear and tear of living, that is to aging.

Between the age of 65 and death, the greatest change is probably in the index of refraction of the lens itself, and the result is a shift toward myopia again, the change being of the order of 2.37 diopters on the average, or 0.10 diopter per year.

It is possible to generalize from the foregoing data as follows: The average infant at birth is far-sighted and his far-sightedness increases up to the age of seven. At age seven, the individual begins to lose his far-sightedness and by the time age 30 is attained, most of it has disappeared. Between 31 and 64, the aging process produces a gradual return of far-sightedness. After age 65, the changes of senescence are generally in the direction of near-sightedness or at least a reduction in far-sightedness. These generalizations are substantiated by any number of studies.

The decrease in hypermetropia or far-sightedness and the increase in myopia or near-sightedness during the first 30 years of life is well shown in a study by Randall (7).

N	% Hypermetropic	Development Level	% Myopic
1,534	91.26	Infants	2.54
356	81.75	Pre-school	7.86
23,315		1st 3 years school	6.79
	76.0	Elementary school	
3,052		Adolescents	11.4
	56.0	Higher schools	

Randall (7) also studied the reports of 115 previous investigators who had studied a total of 146,522 subjects and found the data substantially in agreement with his own. He was also able to conclude that myopia or near-sightedness increased most rapidly between the ages of 7 and 12 years.

Scobee (8) studied 609 children in the sixth grade, the average age being 11 years, and 606 in the first grade, the average age being 6 years. All 1,215 children were refracted under homatropine cycloplegia and the incidence of hypermetropia, emmetropia, and myopia is of interest.

	Age 6	Age 11
% Hypermetropic	91.7	82.5
% Emmetropic	5.0	9.5
% Myopic	3.3	8.0

Another study having to do with growth changes in the human eye is that of Ciocco (1). He examined each of 1,481 school children on two occasions 2 1/2 years apart. His findings may be summarized in the following table.

Refractive Error Type	% First Examination	% Second Examination	% Change
Emmetropia	2.2	2.1	None
Hypermetropia	68.1	55.3	20
Myopia	3.6	6.2	70
Hypermetropic astigmatism	23.3	32.5	40
Myopic astigmatism	1.5	2.4	65
Mixed astigmatism	1.4	1.4	None

There have been innumerable studies purportedly of refractive error in school children but few have been based upon cycloplegic refraction; instead, they have relied largely upon visual acuity with the assumption that the hypermetropic child can usually see 20/20 while the myopic one cannot. The fallacy here is obvious. Kempf (5) and his associates highlighted this fallacy in a study in which 66% of children in the sample had visual acuity of 20/20 or better without cycloplegia; under cycloplegia, only 21% had 20/20 or better while 32% fell to a level of 20/50 or worse. The ability to see 20/20 in the absence of symptoms of visual fatigue (asthenopia) is certainly no proof of the existence of emmetropia, a conclusion erroneously reached by many investigators.

It might be thought that an undue amount of space has been devoted to the changes in refractive error of the average human eye from cradle to grave. Such emphasis is justified, however, because of the relationship between refractive error and visual acuity. The hypermetropic (far-sighted) person can compensate for much of his refractive error by accommodating excessively and thus frequently secure a level of visual acuity of 20/20. The myopic (near-sighted) individual can do little about his refractive error and the resultant poor visual acuity except squint the eyelids almost shut and this is not particularly efficient. If astigmatism is not too great in amount, accommodation can help compensate in part but a good deal of strain results and the compensation is thus far from satisfactory.

There are four major factors which may be identified in the composition of practically all tests of visual acuity (6). These are: (1) retinal resolution, (2) brightness discrimination, (3) form (letter) perception, and (4) simple form perception. With the exception of some studies which were conducted on the Ortho-rater (checkerboard target), all others to be mentioned in this paper employed Snellen-type letter charts and were thus weighted with the factor of form (letter) perception. The checkerboard target is weighted most heavily toward retinal resolution rather than toward form (letter) perception.

The percentage of individuals able to attain a visual acuity of 20/20 with both eyes increases steadily from birth to the age of 22 years (2, 3, 11, 13). Slataper (11) examined more than 20,000 eyes and the following data are from his paper.

Age	% Having 20/20 Using Both Eyes
3	3
4	8
5	22
6	44
7	52
8	56
9	61
10	69
11	75
12	78
13	81
22	84

The figures of Slataper represent corrected visual acuity, that is, with the subjects wearing corrective lenses whenever needed. There are several other reliable studies of the percentage of the population having uncorrected visual acuity of 20/20 using both eyes but the majority do not have the specific breakdown by age groups that is fortunately present in Slataper's work.

Sloane (13) reported on 1,129 boys between the ages of 13 and 19 years and found that 72 per cent had an uncorrected visual acuity of 20/20 or better using both eyes.

Collins (2) reported on 9,245 school children between the ages of 6 and 16 -- a younger group than Sloane's (13) -- and found 62.9 per cent with uncorrected visual acuity of 20/20 or better using both eyes. Collins and Britten (3) studied a group of 4,862 white boys between the ages of 6 and 16 and found 57.1 per cent at age 6 with 20/20 or better (uncorrected) using both eyes; they also studied 6,479 male industrial workers aged 18 and over. They found 77.2 per cent between the ages of 18 and 20 years whose uncorrected visual acuity using both eyes was 20/20 or better; between 40 and 44 years, the percentage with 20/20 or better fell to 49.5, and in the group aged 60 and over, it fell to as low as 5.5 per cent.

Scobee (8) studied 606 children at age 6 years and found that 53.6 per cent had uncorrected visual acuity of 20/20 or better using both eyes; in a group of 609 children at age 11 years, 67.5 per cent had uncorrected visual acuity of 20/20 or better using both eyes. In the same study, the 609 children at age 11 were also studied on the Orthorater with a checkerboard target; 82.1 per cent were found to have uncorrected acuity of 20/20 or better using both eyes.

After the age of 22, uncorrected visual acuity begins to fall (3, 11).

In Collins' (2) study, slight sex differences appeared. In 4,774 boys, 65.2 per cent between the ages of 6 and 16 years had uncorrected acuity of 20/20 or better; 4,471 girls in the same age range were studied and only 60.5 per cent attained 20/20 or better.

Ely, Kephart, and Tiffen (4) reported work confirming that of Collins (2) with respect to sex differences. Their sample consisted of 7,659 males and 2,469 females in the age range of from 16 to 70, the majority being between 20 and 50; 75 per cent of the males and only 66 per cent of the females had uncorrected acuity of 20/20 or better using both eyes and this difference is significant at the 1% level. They used the Orthorater with a checkerboard test target while Collins used a Snellen chart. In the light of present knowledge, at least, the reason for sex differences in visual acuity is obscure.

In summary, the ability to attain uncorrected visual acuity using both eyes increases steadily from birth to age 22, and then begins to decrease with further advance in age. This

is true of the population as a whole despite the recognized increase of myopia during the early years of life.

It would perhaps be accurate to say that when visual acuity is measured on checkerboard test targets in the Orthorater, about 70 per cent of the male population within the military age range may be expected to attain uncorrected visual acuity of 20/20 or better using both eyes. This would be true irrespective of refractive error. The per cent might be slightly lower if Snellen charts were used for testing. If the estimate is in error, it errs on the side of conservatism. It is to be emphasized that no other visual function save visual acuity is considered in this estimate.

Turning now to a specific consideration of the divisions of the Career-Wise Master Plan (Revised October, 1950) of the Working Group on Human Behavior, only a few added remarks are needed to complete the picture. All of the foregoing material on refractive error and visual acuity has pertained to the national make-up (B-1).

It is obvious that physical standards for enlistment in the armed forces during peacetime should be higher than those for induction during wartime (B-2). In the ideal war machine, any one man may be placed in any one of a number of jobs and perform with reasonable satisfaction in all. If the visual task varies from one job to the next, ideally each man would have the visual mechanism to perform any one of the tasks. It would seem difficult to defend the acceptance of any but individuals with 20/20 visual acuity in a peacetime armed force since such a force is intended to be but a skeleton which may be expanded in wartime and since it is presumed that the members of such a peacetime force will be highly trained in a fairly large number of different jobs.

During wartime with the mobilization of large numbers of men, perhaps total mobilization with all that the term implies, visual acuity standards may be considerably lowered without impairing the efficiency of the fighting machine. Extensive visual studies in industry have shown that there is little drop in the efficiency of the average worker in performing almost any job in industry until his level of visual acuity falls below 20/40. Modern methods of waging war are akin to modern industry in many ways. It would therefore seem logical to set a level of visual acuity of 20/40 in each eye separately as a standard for unlimited military duty during time of war. It is obvious that there are a few highly specialized visual tasks which would require higher levels of acuity, even 20/15 in each eye, but there should be no difficulty in filling these places. A Working Group of the Armed Forces -- National Research Council Vision Committee has recently made just such a recommendation to the Department of the Navy with respect to the commissioning of naval line officers; it is a recommendation which seems justified in view of the evidence of performance already available.

For the individual with visual acuity of less than 20/40, there are still many duties which may be performed with satisfaction within the armed forces in time of war. It is a waste of manpower to reject the individual with very poor visual acuity in one eye, or relatively poor acuity in both eyes provided the cause for the poor acuity is not progressive. It should be obvious that those with acuity levels lower than 20/40 would, for the most part, be kept upon assignments outside of combat areas on all occasions and preferably in situations where there would seldom if ever be a need to shift personnel from one task to another requiring higher visual acuity for even short periods of time.

With respect to general combat duty in all three of the armed services, a visual acuity of 20/40 in each eye separately that is correctible to 20/20 should be sufficient for officer candidates. It is to be emphasized that the individual with an uncorrected acuity of 20/40 in each eye separately will almost invariably have at least 20/30 or better (uncorrected) when using both eyes together.

A majority of the tasks in modern war are essentially near tasks when considered from the visual standpoint. There is a general misunderstanding to the effect that the person whose distant acuity is, say, 20/50 in each eye is unable to see comparatively small objects close to him. There are very few near tasks performed, even in industry, today which demand near acuity any greater than a comparable 20/50 for distance. In those few near tasks demanding very fine near acuity, there are usually optical devices (magnifying) available as a matter of routine.

In the previously mentioned study of Ely (4) and associates, 7,659 males and 2,469 females had their visual acuity measured on an Orthorater. They were pre-selected to the extent that they already had jobs or were making application for jobs in industry. Seventy-five per cent of the males and 66 per cent of the females had visual acuity of 20/20 or better using both eyes. Ninety-nine per cent of the males and 98 per cent of the females had visual acuity of 20/40 or better using both eyes.

The physical demands of military service (B-3) may not be expected to have any permanent significant effect upon visual acuity if one excludes trauma and disease. Mere physical fatigue may have an adverse effect upon visual acuity but this is temporary.

It is possible to apply "conditioning" courses to the eyes (B-4) in several ways, at least one of which has proven value. The work of Low has suggested that it is possible to improve utilization of peripheral acuity through training and that this improved functioning may be maintained over an indefinite period. Such a course of training for lookouts might be beneficial. The value of night vision training was demonstrated in World War II and there is general agreement among informed sources on this point. All men who might conceivably be in combat at night can benefit from a course in night vision training.

Standards of visual acuity for various special jobs (B-5, 6) require an analysis of each job. With the multitude of analyses already performed for industry, comparable but brief studies of military tasks will undoubtedly reveal many areas for application of previously determined industrial standards. The writer happens to be aware that such a study has recently been completed for every visual task aboard a submarine. There is no reason why this could not be done throughout the armed forces.

Comment has already been made with regard to limited service (B-7) and for combat (B-8). Also covered briefly have been the effects of disease and of age upon visual acuity (B-9, 10, 11).

Special Visual Standards (D-2)

Uncorrected visual acuity of 20/40 in each eye separately should prove a suitable level for general military service in draftees, because this usually means at least 20/30 when both eyes are used together and since, in the large majority of instances, it can be corrected to 20/20 or better if this is found necessary.

Cadets for the various academies of the armed forces are usually in their late teens at the time of application. A four-year academic course will be associated with a decrease in hypermetropia or an increase in any existing myopia or a shift from the former to the latter. It therefore seems best to require uncorrected visual acuity of 20/20 in each eye for such applicants plus a spherical equivalent for each eye which is at least on the side of hypermetropia; this should prevent those who may become somewhat myopic during their course from having an uncorrected acuity of less than 20/40 at graduation and they would thus still be eligible for commission as line officers. An exception would be in the case of air cadets since the Air Force is currently demanding uncorrected acuity of 20/15 in each eye for jet pilots; such cadets upon application should have uncorrected acuity of 20/15 in each eye, not more than 0.75 diopter of astigmatism, and a spherical equivalent of not less

than +1.25 nor more than +2.25 diopters. These rather rigid specifications should guarantee that the large majority of cadets would still have uncorrected acuity of 20/15 in each eye separately at the end of a training period of several years. The suggested specifications are for cadets making application between the ages of 18 and 22. For applicants over age 22, the minimum spherical equivalent could be safely dropped to +0.25 with the other requirements remaining unchanged.

MUSCLE BALANCE

The binocular neuromuscular mechanism is that mechanism which controls the movement of the two eyes in order that theymmay move in the same direction at the same time and by the same amount. The very existence of two eyes raises problems which would never be present in a one-eyed individual. A one-eyed individual never suffers from eye-strain since eye-strain arises only from the attempted use of two eyes together simultaneously as a team. An adequate evaluation of the individual's ability to control the position of the two eyes thus becomes essential in an attempt to identify the "normal" individual.

A number of studies in the past have been performed on several age groups of the general population. Before considering these studies, an explanatory remark or two on heterophoria is in order.

An individual whose binocular neuromuscular mechanism is perfect would be one in whom, whether one or both eyes are being used at any one time, both eyes would always be aimed accurately at the object of regard. This means that if an individual is looking at some object across a room and a cover is placed before one eye, the covered eye will nevertheless continue to look in the exact direction of the object of regard. When the cover is removed, the previously covered eye will be found in the exact position for resuming its visual study of the object of regard in concert with the fellow eye. If this simple test is employed (it is known as the cover test), it will be found that practically no individual has a perfect binocular mechanism because, under the conditions mentioned -- covering one eye and then removing the cover -- no individual's eyes remain aimed in the exact direction of the fixation object. If the covered eye deviates, as it does in practically one hundred per cent of the population, the deviation may vary from an almost imperceptible one to a very obvious one. As soon as the cover is removed, the deviation is corrected by the fusion mechanism and the eyes are re-aligned in the direction of the object of regard. Placing a cover before one eye produces dissociation of the two eyes. Any deviation of one eye which appears under these conditions of dissociation and which is promptly corrected as soon as the dissociation is ended is known as heterophoria. Heterophoria is thus a deviation of the eyes which is corrected by the brain, that is, by the fusion mechanism. We have said that heterophoria can be almost imperceptible in some individuals and very great in others. The question which arises, then, is "How much heterophoria may be considered normal?" In other words, where can we set the limits of "normal"; who is normal and who is not?

We have said that no single test of the functions of the visual mechanism, when considered alone, reveals the exact status of that mechanism. This statement is particularly true with regard to muscle balance. We have so far discussed but a single aspect of muscle balance. We have so far discussed heterophoria. A number of studies have been performed in the last quarter of a century on random samples of the population at varying age levels. If one considers a majority of the population as "normal" in terms of distribution curves and the tails of the distribution curve as abnormal, children will have slightly different "normal" scores from those of adults. It is a logical assumption that the child differs from the adult not so much in the make-up of his visual mechanism but in the stability and maturity of that mechanism. It is therefore necessary to comment briefly upon the factors which influence the stability of the visual mechanism before citing actual scores which may be considered normal for children and for adults.

The fusion mechanism is that portion of the cortex of the human brain which controls the functioning of two eyes together as a team and which is responsible for the mental intetration of images received by each eye separately. The fusion mechanism represents the highest and most recent developmental aspect of the visual mechanism. It is a far cry from the lowly worm with a few cells sensitive to light alone to the human eye with all its complexities of differentiation and development. The animal low on the developmental scale who has a few cells sensitive to light obviously has no need for a fusion mechanism because no images are received. No images are received firstly because there are no eyes to form the images and secondly because there is no brain to receive them. As the development of the eye progressed in the evolutionary development of the animal, the eye became more complex and more efficient and the increasing complexity of the eye required a more and more complex controlling mechanism. It was probably thus that the fusion mechanism eventuated. The fusion mechanism can be considered in some ways as the driver of a team of horses. It is he who controls the horses not only with respect to which direction they will go but at what rate of speed. The fusion mechanism is all important to the functioning of two eyes together as a team and it plays a role in many of the other aspects of the visual mechanism. It controls the particular aspect of heterophoria -- a deviation of the eyes which appears when the two are dissociated.

If an individual is to be placed under conditions of stress and strain, as is true in time of war, then it becomes important to know how much the visual mechanism will vary under these unusual conditions. It is a logical assumption that the individual with the ideal visual mechanism will show the least variation irrespective of the immediate environment. The individual who shows a great deal of variation in his visual mechanism under the comparatively ideal and stress-free conditions of peace in which an individual may to a certain extent create his own environment will become increasingly unreliable in time of war. Such an individual with wide variations in the level of function and efficiency of function of the visual mechanism in time of peace is certainly not to be considered dependable under conditions of wartime emotional stress and strain. Since every individual has a certain amount of variation in the function of the visual mechanism, it then becomes important to know how much variation may be considered allowable. We have pointed out that there is slightly more variation in function from the standpoint of muscle balance of the visual mechanism of the child than of the adult.

A tendency of the eyes to deviate inward is called esophoria, a deviation outward is exophoria, and a vertical deviation is called hyperphoria. Children, on the average, are slightly more esophoric than are adults. It is known that esophoria increases with nervous tension. It is more difficult to secure emotional and mental relaxation in a child, particularly a young child, than it is in an adult under the same testing conditions. One might therefore predict that children would on the average be slightly more esophoric than would adults.

Sloane (12) studied a relatively large sample of school children and suggested the following limits of normal for the Maddox rod portion of the Massachusetts Vision Test:

at far:	6 esophoria to 4 exophoria 1.25 right hyperphoria to 1.25 left hyperphoria
at near:	6 esophoria to 8 exophoria vertical phoria same as at far.

In another study, Sloane (13) reported on 1,129 boys between the ages of 13 and 19. Using a Maddox rod test, he found that 94.5 per cent fell between 4 esophoria and 4 exophoria at far, and 94.5 per cent fell between 4 esophoria and 8 exophoria at near.

Scobee (8, 9) found 90 per cent of 598 children in the sixth grade with between 4

esophoria and 8 exphoria at near using a Maddox rod test; 92.2 per cent were between 4 esophoria and 4 exphoria at far. Another sample of 578 first graders was studied on the same test; 92.9 per cent lay between 4 esophoria and 8 exphoria at near, and 90.9 per cent lay between 4 esophoria and 4 exophoria at far. More than 98 per cent of both first and sixth graders lay between 1 right hyperphoria and 1 left hyperphoria at both near and far with a Maddox rod.

Scobee (8) studied the same group of 598 sixth graders on the Orthorater and found that 81.8 per cent lay between 4.5 esophoria and 4.5 exophoria at far; 84.9 per cent lay between 4.66 esophoria and 6.33 exophoria at near. Approximately 96 per cent had between 1 right hyperphoria and 1 left hyperphoria at both near and far.

Ely (4) and associates studied over 7,000 males and over 2,000 females between the ages of 17 and 70 in industry and found that 81 per cent fell between 4.5 esophoria and 4.5 exophoria at far on the Orthorater; at near, 88 per cent of females and 90 per cent of males fell between 4.66 esophoria and 6.33 exophoria on the Orthorater. These figures are quite comparable to those of Scobee (8) cited in a preceding paragraph. Ely (4) also found 95 per cent of both males and females with between 1 right hyperphoria and 1 left hyperphoria on the Orthorater at near and at far.

Grieve and Archibald (15) reported on a sample of 7,019 males between the ages of 17 1/2 and 30 years tested on the Maddox rod at far. They found 94.7 per cent between 4 esophoria and 4 exophoria.

Scobee and Green (10) found 91 per cent of males between the ages of 18 and 35 had between 4 esophoria and 4 exophoria at far with a Maddox rod test; at near, 82 per cent of the same group fell between 4 esophoria and 8 exophoria.

From a statistical standpoint, at least, there seems to be little objection to setting the limits for "normal" heterophoria with the Maddox rod test between 4 esophoria and 4 exophoria for far, and between 4 esophoria and 8 exophoria for near. These limits are substantiated by distribution curves for heterophoria in more than a few studies of various samples of the general population. However, mere heterophoria measurements alone fall far short of telling the entire story about ocular muscle balance. Heterophoria is a deviation of the eyes which is corrected by the fusion mechanism. It is therefore not so important to know the amount of heterophoria present as it is to know the extent of the ability of the fusion mechanism to deal with that same heterophoria. The ability of the fusion mechanism is measured in prism diopters of <u>vergence</u>. If an individual has esophoria -- an inward deviation of the eyes -- then it is important to know the diverging (movement outward) ability of the fusion mechanism which combats the converging movement that is esophoria.

Several studies (16, 17, 18) have shown that the average normal individual will have the following prism vergence values:

1. at far - Convergence......25 diopters
   - Divergence....... 6 diopters

2. at near - Convergence......28 diopters
   - Divergence.......20 diopters

If an individual has esophoria, it is important to know his powers of divergence; if he has exophoria, his convergence powers are of particular importance. Two individuals may both have 4 esophoria at far; one has adequate divergence power and is comfortable while the other has very poor divergence, is frequently a victim of headache, and under conditions of severe stress and strain may actually see double. Both individuals have esophoria that is just within the limits of "normal" and yet one is certainly far from being normal. In

the evaluation of heterophoria, prism vergence must also be determined. Even as much as 10 esophoria, if divergence powers are adequate, is of little significance and such an individual might be expected to perform under stress and strain just as well as the individual with no esophoria at all. Probably the most important of the four vergence measurements to know is prism divergence at near (16, 17, 18). While it does not tell all, it nevertheless gives a great deal of information and if one had to choose one of the four vergence measurements, certainly prism divergence at near would lead the list as being most likely to give an indication of the status of the fusion mechanism. Prism divergence at near of less than 12 is usually indicative of esophoria and poor divergence; more than 26 of divergence at near is usually indicative of exophoria and excessive divergence with probably, but not necessarily, poor convergence.

There is no particularly significant change in heterophoria with age (10) and thus the same limits of "normal" would apply to the man of 20 and the man of 50.

Accommodation power may logically be included in a discussion of muscle balance. Accommodation does decrease with age and the table of norms prepared by Duane over half a century ago is still valid today and is in use by all of the armed forces. It would seem to require no further comment.

Convergence Near Point (NPC). The only bit of evidence which favors measurement of the convergence near point is the fact that it has been measured religiously for almost a century. The test of time in this instance is deceptive. Measurement of the NPC was included in all flying examinations when they were first written and there are still ardent advocates for continuance. There are also many firm believers in divining rods.

In the measurement of the NPC, the examinee literally crosses his eyes. Crossing the eyes is a trick that can be learned. The individual who is unaware of the trick and who actually has poor convergence powers will have his defect revealed upon vergence studies. The individual who knows the trick and who nevertheless has poor convergence powers, if the latter are not tested, may deceive the examiner into thinking he is normal. Vergence measurements are far more reliable indicators of the status of the fusion mechanism than is the near point of convergence. There thus seems to be no good and scientific reason for continuing to include it in any battery of tests of visual functions. Recommendations have already been sent from both the Armed Forces -- National Research Council Vision Committee and the National Research Council's Committee on Ophthalmology to the surgeons general of all three services to the effect that determination of the NPC be dropped.

Turning now to a consideration of specific points about muscle balance in the Career-Wise Master Plan (Revised Oct. 1950), the national make-up with respect to muscle balance (B-1) has already been considered. In World War II, no test of muscle balance was given for enlisted personnel and the lack was hardly noted. Such tests can probably be limited to responsible personnel who are to fill jobs where the task is largely visual, such as pilots, radar operators, fire control operators, etc. Limits for such personnel might well be 4 esophoria to 4 exophoria at far and 4 esophoria to 8 exophoria at near if the Maddox rod test is used and testing technique is standardized. A standardized technique has already been carefully prepared and is available in the Manual on Testing Heterophoria published by the Armed Forces -- National Research Council Vision Committee. Not more than 1 prism diopter of hyperphoria at either near or far should be allowed, in addition to the later limits already suggested. These standards for heterophoria need only be applied to those individuals being considered for specialized visual tasks and probably need not be changed, irrespective of the task. They are also applicable to candidates for academies of the armed forces. Even adequate vergence powers will be somewhat decreased with disease but return rather promptly to normal upon recovery from the contributing illness. Relatively small amounts of heterophoria will become significant and cause trouble if the controlling vergence powers are inadequate; stress and strain of combat may effect a breakdown in

inadequate vergence powers (20). If muscle balance is to be determined at all, both heterophoria and prism vergence should be measured. These few remarks should have completed the coverage of B-2, through 11 with one exception. The exception is "conditioning" (B-). It is possible to increase convergence powers in a majority of the individuals through orthoptic training; thus more men may be made available and others rehabilitated in time of war. At the present time, there is only a single orthopic center within the armed forces and it located at Percy Jones General Hospital, Battle Creek, Michigan. Several more such centers could be used and should be created.

Any consideration of muscle balance would not be complete without mentioning the fact that war injury to the ocular muscles can produce crippling disability in the form of double vision and this may be permanent if not properly treated. It is unfortunately true that the majority of ophthalmologists over the country may perform excellent surgery but few have interested themselves in any intensive study of disturbances of ocular motility, particularly traumatic ones. The average ophthalmologist will see relatively few such cases in a lifetime of practice and the result is that treatment is often delayed or improper. One of the greatest forward strides which the armed forces could make would be, in the event of war, the setting up of a single Motility Center in some general hospital. To such a center could be sent all patients with traumatic paralysis of any of the ocular muscles. Concentration of these patients under a few ophthalmologists would improve care and markedly facilitate rehabilitation of personnel, thus reducing the number of permanent disabilities from this cause. Just as Valley Forge General Hospital became a training center for the blinded during World War II and performed splendidly, so could a Motility Center function.

NON-TECHNICAL SUMMARY

This report is concerned with the visual mechanism and its particular aspects of visual acuity, refractive error (far-sightedness, near-sightedness, astigmatism), and muscle balance. Comparatively large samples of the general population have been studied by many investigators and their findings are summarized. Similar but smaller samples of the potential military population have also been studied. The discussion is concerned with the numbers of the male population (in terms of percentages) which might be available to the military in the event of total mobilization considered from the standpoint of the visual mechanism. Information about the normal development of the visual mechanism as it is known today is included and recommendations for certain visual requirements have been made on the basis of this information.

Probably one of the most significant points to be made is that the old idea of a mans' having to have visual acuity of 20/20 in each eye to perform satisfactorily in wartime no longer seems valid. Both clinical and industrial experience has shown that the large majority of persons with visual acuity of 20/40 can perform practically all visual tasks satisfactorily. If acuity levels of better than 20/40 are needed for highly specialized tasks, approximately 94 per cent of the potential military population can be brought to 20/20 with correcting glasses.

No tests of muscle balance would seem to be required for general combat duty. However, pilots and other personnel who may be expected to perform tasks in which the visual role is particularly important should be given tests for muscle balance to insure proper selection of men with a minimum of waste in training time and effort. Specific recommendations include the use of the Maddox rod test for heterophoria with the following limits:

1. Far -- between 4 esophoria and 4 exophoria and not more than 1 hyperphoria.

2. Near -- between 4 esophoria and 8 exophoria and not more than 1 hyperphoria.

If a machine test, similar to an Orthorater, is used, the same limits could be applied almost without change.

Prism vergence should also be determined, at least prism divergence at near. An individual to perform satisfactorily should have not less than 12 nor more than 28 diopters of prism divergence at 13 inches. These two requirements -- heterophoria and prism divergence -- would screen out the large majority of those who could not perform tasks requiring intense and accurate visual effort satisfactorily.

Tests of accommodation, graded with respect to age, should also be required of those expected to perform largely visual tasks.

There is no good reason to continue measuring the near point of convergence.

This paper does not discuss depth perception and color vision.

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SOME ASPECTS OF PROBLEMS OF VISUAL STANDARDS

Benjamin J. Wolpaw

A. SPECIAL VISUAL STANDARDS IN PROCUREMENT, RECRUITMENT, AND INDUCTION OF MILITARY PERSONNEL IN ALL BRANCHES OF THE SERVICES.

To set up visual standards which would fit each duty in the military services would be a hopelessly impossible task. There would be almost as many sets of standards as there are duties.

There must be a distinction drawn between the non-combat and combat man in the Ground Forces, the airborne and ground man in the Air Forces, and the shorebound and sea going man in the Navy. The main differentiation in the above groups is that the uncorrected vision is of no importance in the shorebound and grounded non-combat man. In this group we are primarily interested in requiring sufficient corrected vision to carry out a task. In the combat and seaborne man we must consider requiring sufficient distant vision to provide reasonable safety in case of sudden loss of glasses. It should not be necessary during combat to assign a man to lead another who has dropped or lost his glasses.

In the past emphasis was placed only upon distant vision. Modern warfare with the increasing use of radar viewed at close range, and the repair of precision instruments in combat areas requires that we give thought to near vision.

With the speed of jet and supersonic planes thought must be given to changing the requirement for pilots of these planes so that at least one eye has 20/15 vision.

A study was made of the one hundred and ten "Rates" in the Navy, and their subsidiary "Ratings." An attempt was made to correlate the duties involved with the visual skills which would be necessary, based on the findings of Kuhn[1] in a study of forty thousand men in industry. This large group of men had all been subjected to a battery of tests such as is recommended for all personnel in the Armed Forces.

These tests are:

1. Visual acuity
   (a) Far - with and without glasses
   (b) Near - with and without glasses

2. Muscle balance
   (a) Far
   (b) Near

3. Depth perception

4. Color vision

5. External examination

6. Examination of retina

This battery of tests, employing the Armed Forces - NRC Vision Committee testing device and color plates can be administered in seven or eight minutes.

Based upon the study of the Navy Rates and with the use of data obtained from the

above battery of tests four major tests of visual standards would encompass all of the requirements for "Procurement and Recruitment."

Group A.
1. Uncorrected distant vision of 20/20 in each eye
2. Near vision uncorrected or corrected to 20/20 in each eye
3. Distance muscle balance between five degrees esophoria and five degrees exophoria
4. Near muscle balance between two degrees esophoria and eight degrees exophoria
5. Hyperphoria of no more than one diopter (for Air Corps)
6. Presence of stereopsis
7. Recognition of basic colors; red, green, blue, yellow
8. No diplopia with red lens test (Air Corps)

Group B.
1. Uncorrected distant vision 20/40 in one eye, 20/50 other eye
2. Corrected distant vision 20/20 in one eye, 20/30 in the other eye
3. Near acuity uncorrected or corrected to 20/20 in one eye, 20/30 in other eye
4. Recognition of basic colors; red, green, blue, yellow

Group C.
1. Uncorrected vision 20/200 each eye
2. Corrected distant vision 20/20 in one eye, 20/30 in other eye
3. Corrected near vision 20/20 in one eye, 20/30 in other eye
4. Near muscle balance between two degrees esophoria and eight degrees exophoria

Group D.
1. Uncorrected distant vision 20/200 each eye
2. Corrected distant vision 20/40 each eye

A study of the above four groups will show Group "A" to be for those services requiring excellent visual skills such as the Air Force, Gun Pointers, Spotters, or Range Finder Operators. Group "B" for those tasks requiring sufficient uncorrected vision to be safe without glasses in time of emergency such as, Damage Controlmen and Air Controlmen. Group "C" includes those whose tasks are primarily at close range. Group "D" will include the large mass of men whose duties do not involve continuous close work or very fine detail such as stewards, messengers and orderlies.

The induction of personnel poses another problem. It is from this group that the majority of non-combat personnel will be obtained for the Navy and Air Force. However, the Army must, of necessity, obtain the majority of its men from this group. For the induction of personnel and the following is recommended:

A. General Duty
   1. Uncorrected distant vision 20/200 each eye
   2. Corrected distant vision 20/40 each eye

B. Limited Duty (Non-Combat)
   1. Subjects with two eyes
      a. Uncorrected distant vision, no limitation
      b. Corrected distant vision 20/40 each eye
      c. Corrected near vision 20/30 each eye

2. Subjects with one correctible eye
    a. Uncorrected distant vision 20/200 in one eye
    b. Corrected distant vision 20/20 in one eye
    c. Corrected near vision 20/20 in one eye

It should be noted that in the two-eyed non-combat requirements no limit is set on the uncorrected vision. As long as the 20/40 corrected vision is obtained the uncorrected vision is unimportant.

An eye which cannot be corrected to better than 20/200 is of little more use than no eye. This fact is recognized by the Internal Revenue Department and by the majority of states in allowing deductions for blindness. Hence, an individual with two eyes, one of which cannot be corrected to better than 20/200 should be considered in the same category as a one-eyed person.

The one hundred and ten "Rates" in the Navy were analyzed in the light of four major requirement groups outlined previously. The Army and Air Force Rates were not included because of lack of sufficient data. However, the duties in the three services are sufficiently comparable that the same standards will apply. Each "Rate" was assigned a letter corresponding to a group in the previously outlined requirements.

Group:	Rates and Ratings:
C	Aerographer's Mates
B	Air Controlmen
B	Airmen
B	Airship riggers
A	Aviation Boatswain's Mates
C	Aviation Electrician's Mates
B	Aviation Electronicsmen
C	Aviation Electronics Technicians
C	Aviation Machinist's Mates
C	Aviation Ordnancemen
B	Aviation Photographer's Mates
A	Aviation Pilots
C	Aviation Storekeepers
C	Aviation Structural Mechanics
B	Boatswain's Mates
C	Boilermen
C	Bookers (Motion Picture Service)
C	Builders
C	Chemical Warfaremen
C	Commissarymen
C	Communications Technicians
C	Construction Electrician's Mates
C	Construction Men
B	Damage Controlmen
C	Dental Technicians
C	Disbursing Clerks
C	Draftsmen
C or D	Drivers

C	Electrician's Mates
C	Electronics Technicians
C	Enginemen
C	Fire Controlmen
C	Fire Control Technicians
B	Fire Fighters
C	Firemen
C	Gunner's Mates
C	Hospital Corpsmen
C	I. C. Electricians
C	Instructors (Miscellaneous)
C	Instrument Men
C	Journalists
C	Lithographers
C	Machine Accountants
C	Machinery Repairmen
C	Machinist's Mates
C	Master at Arms (Shore)
C	Mechanics
C	Metalsmiths
C	Minemen
C	Molders
C	Musicians
C	Opticalmen
C	Parachute Riggers
C	Patternmakers
C	Personnel Men
B	Photogrammetry Assistants
C	Photographer's Mates
B	Physical Training Instructors
C	Pipe Fitters
C	Printers
B	Quartermasters
C	Radarmen
C	Radiomen
D	Seamen
C	Ship's Servicemen
C	Shore Patrolmen
C	Sonarmen
B	Specialists
C	Steelworkers
C	Stewards
C	Storekeepers
C	Surveyors

C	Telemen
A	Torpedoman's Mates
C	Tradesmen
C	Transport Airmen
C	Transportation Men
A	Underwater Mechanics
C	Utilities Men
C	Welfare and Recreation Leaders
C	Yeomen

It would be obviously impossible to refract every subject at recruiting or induction stations. However, if at these stations the complete battery of tests were administered to each subject a long step forward would be taken in proper placement. Those obviously unfit could be quickly ruled out. Those whose other talents and training qualified them for a certain duty would quickly show from the battery of tests whether they have the necessary visual qualifications.

In the suggested visual requirements for each "Rate" consideration was given only to combat personnel. Many of the duties assigned to Group "C" such as Yeomen, or Radio Operators could be filled by one-eyed subjects or those with less than 20/200 unoorrected vision in both eyes for the non-combat personnel.

There are very few duties in the Armed Services which cannot be carried out by subjects wearing glasses. These duties are chiefly those in the Navy where men are subject to salt water spray, steam, or are underwater.

Although service regulations have always required a certain degree of corrected vision, it should be realized that no regulation has compelled the men to wear their correction. Hence, our services have always fought with vision below the required corrected standard. It would be of considerable value to make surprise examinations of visual acuity of personnel in order to determine how well the work is being carried out by men who are supposed to be wearing a correction but do no do so.

The services at present require better visual acuity for men entering the field of electronics and for the women's services than is required for general duty. The basis for this is that this personnel carry out more detailed close work and hence require better vision. The basic concept is correct, however it is completely erroneous to require better distant vision for personnel whose duties are in the near range. A far-sighted subject with 20/20 vision in each eye may be unable to do desk work comfortably, whereas the near-sighted individual with 20/200 vision could do desk work or instrument repair work without any difficulty. It is to correct this error in examination that stress is laid, in this paper, upon the necessity for testing near as well as far vision.

The testing of color vision is not for the purpose of disqualification. No subject need be rejected for poor color discrimination. The test is administered:

(a) For purposes of record
(b) To acquaint the subject with the fact that he has a color defect
(c) For aid in proper placement

The use of personnel with uncorrected vision below present requirements, in a non-combat status, would free for the active combat forces a much higher percentage of subjects in the better vision groups. This program should not reduce the efficiency in the non-combat duties and should increase the efficiency of the combat forces.

SUMMARY:

1. A schedule of visual requirements for duty in the Armed Forces has been outlined.

2. Each inductee and enlistee should be subjected to a rapid battery of tests of visual skills.

3. The results of the tests will materially aid in proper personnel placement.

4. The increasing use of the eyes at near range makes a near vision test more imperative than in the past.

5. In non-combat personnel there need be no limitation on uncorrected vision.

Note:

1. Kuhn, H. S.: EYES AND INDUSTRY.

B. UTILIZATION OF PERSONNEL WITH VISUAL DEFECTS ON NON-COMBAT DUTIES.

For every man in combat various reports have shown that there are fifteen to twenty men in non-combat duties.

In the past the same visual standards have been applied to all subjects at recruiting or induction stations. These standards by and large have been based upon the needs of the combat man. This either eliminated those subjects who could not meet combat necessities, or kept physically perfect men at tasks which could equally well be carried out by subjects with non-disabling defects. Variations from the normal can only be considered a defect when applied to the task which a subject must perform. In an aviator 20/40 vision would be defective, however, the same vision in an orderly or mess attendant or in a radio mechanic repairing equipment would not be a handicap.

Unfortunately no job analysis of visual requirements has ever been carried out for all of the tasks in the Armed Forces. Hence, we must turn to industry where an excellent start has been made in coordinating a job with required visual skills.

The following classification set up by Kuhn[1] and based upon the study of about forty thousand men and women in industry would include the majority of non-combat personnel in the services.

Group 1. -- Clerical and Administrative
1. Corrected distance acuity, 20/40 each eye
2. Corrected near acuity 20/30 each eye
3. Normal muscle balance for near
4. Whether individual has normal distance muscle balance or normal depth perception is not of importance
5. Color discrimination is not important unless individual is working with colored file cards or colored materials.

Group 2. -- Vehicle Operators (Tractors, trucks, cranes, etc.)
1. Corrected distance acuity, 20/30 each eye
2. Normal distance depth perception
3. Normal color discrimination (IF the individual uses color signals)
4. Normal muscle balance for distance

5. Degree of near acuity depends on whether individual needs to handle orders, make recordings (bifocals are contraindicated on crane operators)

Group 3. -- Close Machine Work, Inspectors

1. Corrected 20/40 each eye distance acuity (actually degree of distance acuity important only for safety reasons not for work requirements)
2. Corrected near acuity, 20/30 each eye (20/15 may be essential at times)
3. Normal near muscle balance
4. Normal color discrimination if inspection includes color evaluation
5. Distance muscle balances not important

Group 4. -- Machine Operators

1. Corrected distance acuity, 20/40 each eye
2. Corrected near acuity, 20/30 each eye
3. Normal depth perception
4. Normal near muscle balance
5. Color not of importance unless special requirement

Group 5. -- Mechanical and Skilled Trades

1. Corrected distance acuity, 20/30 each eye
2. Corrected near acuity 20/25 each eye
3. Normal near muscle balance
4. Normal depth perception
5. Normal color appreciation (if colors are used in operation)

Group 6. -- Labor

1. Corrected distance vision 20/50 each eye
2. Degree of near acuity -- not important unless individual has to read orders, then should have corrected 20/30 each eye
3. Near muscle balance -- not important
4. Distance muscle balance -- not important
5. Depth perception -- not important
6. Color -- not important, unless some special danger requires recognition of green-red signals

It should be noted that no reference is made to the uncorrected or naked eye vision. In a non-combat subject, who is in no immediate danger should his glasses be broken, it makes little difference whether his uncorrected vision is 20/80 or 20/800. We are only interested in the visual acuity on the job with glasses. Thousands of men who could not meet the above qualifications have been disqualified in the past because they could not meet a certain uncorrected vision standard. There need be no limitation on uncorrected vision in non-combat personnel who can meet the above standards with glasses.

The problem of one-eyed subjects is more difficult. It will be noted that in the above classification no mention is made of monocular individuals. When industry hires a one-eyed subject it faces the penalty of being responsible for producing blindness should injury cause the loss of the eye. The monetary assessment against the industrial concern is far greater than if one eye is lost in a two-eyed subject. Hence, except during times of great emergency industry shies away from employing the one-eyed man.

The Armed Services, however, have numerous non-combat tasks which can safely and efficiently be carried out by the one-eyed subject. A few of these are orderlies, messengers, filing clerks, desk workers, mess attendants, parachute riggers, and land based radio operators. For this group of monocular individuals a requirement of 20/200 uncorrected and 20/20 corrected vision would suffice.

"First, if defects exist, relate them to placement. Second, if defects exist correct them when possible. Third, if it is not possible to correct these defects, find that spot in a plant where that individual can do the job in spite of his defects". This statement, by Bartle[2], can well be applied to eye defects in non-combat service personnel.

Borrowing data from industry[1] we can say that job efficiency will suffer unless we meet the following general standards:

1. Vision 20/40 or better corrected
2. The presence of stereopsis in those whose occupation involves judgment or distance
3. A muscle balance within the ranges of two degrees esophoria to eight degrees exophoria for near; and three degrees esophoria to five degrees exophoria for distance.
4. Color deficient those who are unable to recognize red-blue-green-yellow colors

The Navy Eye Correction Program[3] has set a good example with its civilian employees. If this program were to be extended to military personnel it would simplify the assignment of subjects to the proper task.

The program requires the examination of employees on one of the modern screening devices such as the Bausch and Lomb Ortho-Rater or the American Optical Company Sight Screener. By this examination all needed information relative to the employee's vision is obtained in seven or eight minutes. The non-combat personnel in the services, in general, carry out tasks very similar to those of the civilian employees at camps, stations, and bases. The improved efficiency of civilian employees assigned to tasks in keeping with their capabilities would also be present in service personnel.

The need for a survey of job versus visual skills in the Armed Forces cannot be over emphasized. A working committee of the Armed Forces - NRC Vision Committee should be set up to conduct a job analysis intended to show the required visual skills for each particular job. Only after such a survey is carried out will it be possible to properly utilize subjects with special visual defects.

SUMMARY:

Subjects with special visual defects can be utilized in non-combat duties to a very great extent if their visual possibilities are correlated with the demands of particular duties. This can best be accomplished by:

(a) Carrying out of a job survey vs. visual skills
(b) Subjecting each man to a battery of tests on the Armed Forces - NRC Vision testing device
(c) Assigning each subject to the task to which the survey shows his visual skills to be best suited.

NOTES:

1. Kuhn, H. S.: EYES AND INDUSTRY.
2. Bartle, Harvey: INDUSTRIAL HEALTH CONFERENCE, Chicago, 1943, A. M. A.
3. Saunders, C. E.: NAVY EYE CORRECTION, EYE PROTECTION PROGRAM, Tr. Am. Acad. Ophth., May-June, 1948.

C. DETERMINATION OF SPECIAL VISUAL DEFECTS FOR SPECIAL CLASSIFICATION AND AND ASSIGNMENT

In the classification and assignment of personnel it is necessary that certain data be obtained with regard to the status of the individual's eyes.

The data required is:

1. Visual acuity
   (a) Far - with and without glasses
   (b) Near - with and without glasses
2. Muscle balance
   (a) Far
   (b) Near
3. Depth perception
4. Color vision
5. External examination
6. Examination of retina

In obtaining this data accuracy is a prerequisite. Speed in testing without loss of accuracy is a second requisite. In the mass testing of large numbers of men the examiner is always under pressure to complete one examinee and to proceed to the next.

Until a few years ago each of the above tests was carried out on a different instrument. Vision was measured with the Snellen Chart. The results were grossly inaccurate. Some charts were clean others yellow with age. Some were properly illuminated, others merely hung next to a window. The muscle balance was measured only in applicants for the Air Service as a routine procedure. The instrument employed, the Phorometer, produced undependable results especially in the hands of inexperienced examiners. Color vision was tested by the use of standard color plates which were available to anyone and hence easily memorized.

The services can best accomplish their purpose by obtaining all of the above information in one battery of tests. All of the data can be obtained in seven to eight minutes with the use of a vision testing device recently developed by the Armed Forces - NRC Vision Committee.

This instrument employs the Ortho-Rater as made by the Bausch and Lomb Company with testing plates developed by the Armed Forces - NRC Vision Committee.

With the use of this instrument there will be reduced to a minimum the variation in results obtained regardless of where a subject is examined. The plates are always clean and the illumination is always constant.

There is a definite need for each of the above special tests of manpower is to be wisely employed in the Armed Services.

(a) The distance vision is necessary as a matter of official record. It is a requisite in placement for duties involving distant vision such as vehicle operators, machine shop workers and the reading of gauges and dials located at some distance above the floor.

(b) The Near vision test is now necessary because of the increasing use of radar screens which are viewed within twelve to twenty inches. Many of the complaints during World War II of eye fatigue by radar observers were in no way associated with the radar screen, but were due to the inability of certain eyes to accommodate and converge for four hours on any object at close range.

The near vision is also important in the desk worker who must accommodate at fifteen inches for several hours at a time. The filing clerk, stenographer and small instrument repairman all of whom require chiefly good near vision. It is very possible to have 20/20 vision in each eye for distance and yet be unable to work at fifteen inches comfortably.

(c) The muscle balance is of importance in personnel whose work is essentially at close range. This group will include all duties requiring fixation of vision at thirteen to twenty inches.

(d) Depth perception tests are not sufficiently accurate to determine percentage of stereopsis, however, the test should eliminate those who do not have stereopsis. These subjects without depth perception make poor vehicle, tractor and crane operators.

(e) Color vision testing is necessary for the assignment of personnel to tasks such as carried out by aircraft mechanics who recognize wire circuits by color bands, ship repairmen who recognize pipes by color bands, signalmen who read signal flags or must recognize the color of red, green, and white flares. A major purpose in testing color vision is not to disqualify a man, as much as to acquaint him with the fact that he has a color defect and should guide himself accordingly.

(f) The external examination of the eye is for the prupose of eliminating those subjects with obvious pathological defects or disease processes and for the purpose of noting on the health record any condition present at the time of entry into the service.

Disqualifying conditions even for non-combat personnel would be those such as marked inversion of eyelashes, ptosis of eyelids, chronic infection of tear sac, marked nystagmus, and trachoma.

(g) The examination of the retina can be carried out satisfactorily in the vast majority of subjects without dilating the pupils. This examination should be carried out so as to record any abnormal process on the health record, and to disqualify subjects who may have lesions, such as retinal detachments, retinitis, and colobomas, in retinal areas required for their duty.

The above tests are the minimum which will uncover special eye defects and aid in the dlassification and assignment of personnel. The entire battery of tests can be carried out with the Vision Committee testing device and the Armed Forces Color Vision Test in little more time than has been required for the Snellen Chart alone. The data can be transferred to an IBM card as a permanent record for use at any time subjects are required for a special task having certain eye requirements. The services can be assured that if the six basic tests outlined herein were carried out upon all personnel entering the military services, and if duty assignments were made upon the basis of visual requirements for that particular duty, there would be few subjects who would fail in their tasks because of visual difficulties.

In the Air Service for flying personnel the Red Lens Test to rule out double vision is important. This will eliminate the subject with a paresis or muscle defect which would produce double vision when looking laterally, up or down.

There is no satisfactory test for night vision at present. Many tests have been devised, however, none are able to correlate the results of a machine test with the ability of a man to see at night.

SUMMARY:

For special classification and assignments certain visual defects must be determined. These tests are:

1. Visual acuity
   (a) Far - with and without glasses
   (b) Near - with and without glasses
2. Muscle balance
   (a) Far
   (b) Near
3. Depth perception
4. Color vision
5. External examination
6. Examination of retina

These tests can beccarried out with consistent accuracy with the use of the Armed Forces - NRC Vision Committee Testing Device and Color Vision Book. The examination will provide a permanent accurate record available for use without the necessity of re-examining subjects prior to each assignment.

TECHNICAL MEMORANDUM, November 20, 1951

Subj.: Sense Research Unit, National Defense Research Council, Soesterberg, The Netherlands.

Prepared by Henry A. Imus

With the financial support of the National Defense Research Council of The Netherlands, Dr. M. A. Bouman is conducting a comprehensive, fundamental research program in sensory psychophysiology relevant to military problems. Studies are being made on the proper color and intensity of flares for best visibility under operational conditions; the contrast thresholds for the dark adapted eye in connection with the use of "sniper scopes"; the absolute threshold of visibility of the red light used in preserving night vision; the effect of dark adaptation of one eye upon the sensitivity of the other; the visibility of moving targets; night myopia relative to fatigue after prolonged radar watches; night vision testing and training; selection methods for night vision and color discrimination and visual acuity; and the nervous and photochemical aspects of vision.

Dr. M. A. Bouman is the Director of the Research Unit which is quartered temporarily in new laboratories of the Royal Dutch Air Force. His laboratory is well equipped and has a good shop in which special apparatus is constructed. There are five technical assistants working with him.

Arrangements have been made with Dr. G. J. Sizoo, President, National Defense Research Council, The Hague, for an exchange of information on research in the general field of psychophysiology on an unclassified basis. Manuscripts and reprints of the reports of research by Dr. Bouman will be forwarded to the London Branch Office. Office of Naval Research reports will be sent to Dr. Sizoo for transmittal to Dr. Bouman.

The following reprints and manuscripts of reports by Dr. Bouman, et al., are being forwarded to the Psychophysiology Branch, Office of Naval Research, Washington, for consideration by the Naval Research Advisory Panel for Psychophysiology:

Bouman, M. A., "Quanta Explanation of Vision," Doc. Ophthalm., 4, 23-115 (1950). (Monograph, Doctoral Thesis)

Bouman, M. A., "Peripheral Contrast Thresholds of the Human Eye," J. Opt. Soc. Am., 40, No. 12, 825-832 (Dec., 1950)

Wassink, E. C. and Bouman, M. A., "Can Phototropism be Initiated by a One Quantum-per-Cell-Process?" Enzymologia, Acta Biocatalytica XII, 20, 193-197 (1947)

Bouman, M. A., "Peripheral Contrast Thresholds for Stimulation of Rod and Cone System by Background and Test Object Separately." Submitted to the J. Opt. Soc. Am. for publication. (Manuscript)

Fischer, F. P., Bouman, M. A. and ten Doesschate, J., "A Case of Tritanopy." Documents Ophthalmologica, Vol. V-VI, 1951, pp. 73-87.

Bouman, M. A. and ten Doesschate, J., "Nervous and Photochemical Components in Visual Adaptation." (Manuscript)

Bouman, M. A. and van den Brink, G., "On the Integrate Capacity in Time and Space of the Human Peripheral Retina." (Manuscript)

Bouman, M. A. and van den Brink, G., "On Night Myopia." Submitted to Ophthalmologica for publication. (Manuscript)

Bouman, M. A., ten Doesschate, J. and du Marchie Sarvaas, G. J., "A Modification of Goldmann's Apparatus for the Objective Determination of the Visual Acuity." Ophthalmologica (Karger, Basel), Vol. 122, 1951, pp. 368-375.

Kremer, P., "Rapport over een Methode voor Quantitatief onderzoek van Subnormal Kleurenzien en de Apparatuur voor Haar Practische Toepassing." (Manuscript)

AN EXCERPT FROM

MEDICAL RESEARCH COUNCIL, APPLIED PSYCHOLOGY RESEARCH UNIT
TECHNICAL REPORT ONRL-119, 51, ONR LONDON

Prepared by Henry A. Imus

VISUAL DISPLAY PROBLEMS

The effects on performance of radar scope observers of the position of the scope, whether straight ahead, straight down or at a position of 45 degrees, are being studied by Fraser[1]: The fewest errors occur when the scope is straight ahead, and when it is straight down. The differences are statistically significant between the vertical and 45 degree position, and between the vertical and the horizontal positions of the scope face. A new device to supplant the "clock test" of Mackworth, which has been sent to Singapore, is being developed for this study.

The threshold of detection of change in velocity of a moving object is being measured by Hick[2]. Over a wide range of initial speeds he found that the increase in speed required to be detectable was about one-tenth of the initial speed. For the easiest detection, the change should be in the middle of an exposure period of not less than one-half second.

The importance of synthetic training for radar operators led to the development of an optico-mechanical simulation of the radar display. Gibbs is studying the effects on the speed of learning and breadth of experience provided by the apparatus in terms of changes in the number of targets, their speed of approach, their visibility on the screen, and the sector and time intervals of their appearance.

Hick[3] developed a special binocular for purposes of search for aircraft. With this binocular, one eye always sees the horizon, which serves as a steady reference plane while the other eye is engaged in searching the sky at a given elevation.

REFERENCES

1. The Relation between Angle of Display and Performance in a Prolonged Visual Task. D. C. Fraser. Quart. Jour. Exp. Psychol., 4, 176 (Nov., 1950).

2. The Threshold for Sudden Changes in the Velocity of a Seen Object. W. E. Hick. Quart. Jour. Exp. Psychol., 1, 33 (Feb., 1950).

3. An Aspect of Searching with Binoculars. W. E. Hick. (A. P. U. 140/50), (Sept., 1950).

AN EXCERPT FROM

NOTES ON SOME OPHTHALMOLOGICAL RESEARCH IN EUROPE
TECHNICAL REPORT ONRL-129-51, ONR LONDON

Prepared by George K. Smelser

METHOD FOR OBJECTIVE DETERMINATION OF VISUAL ACUITY

Some years ago Professor Hans Goldman of the Universitäts Augenklinik, Berne, developed an objective method for the detection of visual malingering which had many features to recommend it. Recently this method has been improved.

The method uses the production of nystagmus as an objective criterion of sight. A moving pattern, which can be distinguished from the surrounding background with normal visual acuity, is used as the fixation object.

The apparatus consists of a large panel which is perforated by an aperture of about 4"-5" x 18". Behind the panel and filling the aperture is a white screen which is moved up and down mechanically through an excursion of approximately 8" some 60 times per minute. This screen is covered by black dots. Originally a checkerboard pattern was used. The dots in the central area are larger than those above and below, so that they are easily distinguishable from the others, even by an individual with moderately defective vision at a short distance, but are not apparent even to a normal person at a distance of about 20 feet. The total light reflected from the area of the large and small dots must be the same.

In making a test the subject is first given a standard visual acuity test and is then seated in a movable chair before the apparatus, and is requested to fix on the obvious patch of larger dots which is moving up and down. The physician observes the subject's eye with an ophthalmoscope to observe the vertical nystagmus which is induced by the moving chart. In practice the room may be darkened and the subject given some object such as the transformer of the ophthalmoscope to hold and occupy his attention. When the nystagmus induced by the moving fixation object has been noted, the chair and the subject are slowly moved backwards until the nystagmus ceases because the subject's visual acuity is insufficient to resolve the dots of the moving pattern. If the diameter of the dots and their distance from the subject is known, visual acuity can be determined. If the subject is a malingerer, a discrepancy will be found between the claimed acuity determined by the routine test methods and the one shown by this test. If the subject is aware of the test method he may attempt to confuse the examiner by fixing to one side of the moving dot pattern and thus avoid a nystagmus. However, if he does so (1) the examiner will be able to detect the shift in fixation and (2) he must do so at the correct distance from the screen. If the screen is changed so that dots of different sizes are used, this will become an almost impossible accomplishment.

In addition to Goldman's own modification another has been devised by M. A. Bouman, J. ten Doesschate and G. J. du Marchie Sarvaas, at the Research Unit at Koningskade 12, The Hague, and the Ophthalmological Institute, Utrecht. These workers found that it was difficult to secure a reflection of light from the test object (large dots or squares) equal to that reflected from the surrounding surface. They devised a test object of black dots 1/2 mm. in diameter and 2 mm. apart covering an area 5 x 3 cm. The background of the movable panel on which these dots were placed was a homogeneous white. Holes were drilled through the panel between the black dots, through which a bright white surface behind the panel could be seen. By varying the brightness of this background, a good match between the brightness of the test object and the surrounding background could be obtained.

These workers point out several possible difficulties in the practical use of the Goldman method: (1) when an individual with normal visual acuity is tested the distance between the patient and the test object, at the limit of his acuity, is so great that the nystagmic movements are hard to see, (2) methods of observations of slight nystagmus are difficult. If a light is thrown on to the eye in order to aid the observer it may dazzle the subject and therefore interfere with the test, (3) at a distance of twenty feet the test object must be seen precisely in the macular region and is easily lost.

The sensitivity of this method of determining visual acuity is almost equal to the ordinary subjective methods. It has been tried and appears to be a valuable diagnostic supplement.

THE CHARACTERISTICS OF TRITANOPIA
TECHNICAL REPORT ONRL-1-52, ONR LONDON

Prepared by Henry A. Imus

For the past twenty-five years, Dr. W. D. Wright who is Professor of Technical Optics in the Department of Physics of the Imperial College of Science and Technology, London, has been interested in the study of anomalies of color vision. With the cooperation of the editors of an English illustrated weekly paper (Picture Post, 12 May 1951), Dr. Wright published a color confusion chart for testing tritanopia which had been developed by Lieutenant Commander Dean Farnsworth of the Naval Medical Research Laboratory, New London, Connecticut. Several other color test charts and a short explanatory article on color blindness were included. Thus, some nine million readers had the opportunity of testing themselves and reporting to Dr. Wright if they had difficulty in reading the tritanopia chart.

This type of defective color vision is extremely rare, and very little quantitative information has been obtained by scientists working in the field of physiological optics. The absence or inactivity of the blue receptors in the retina are assumed to be responsible for this deficiency. This is different from the red-green types of color blindness, protanopia, in which the red-receptors are thought to be absent, and from deuteranopia, in which it is believed a fusion of the red-green processes occurs.

About nine hundred responses were obtained from the publication of this article. Of these, four hundred reported difficulties which indicated that they had a red-green type of color blindness. Another three hundred reported some difficulty with the color charts. Of fifty persons whose responses pointed strongly to Tritanopia, Professor Wright has tested twenty four, of whom sixteen were found to be tritanopic. Using the usual statistical analyses of responses from this kind of survey, and assuming that half of the remainder may have this defect, he estimates that the percentage of occurrence in the general population is 0.0004%. The estimate of the frequency of occurrence varies from 1 in 12,000 to 1 in 60,000, depending upon whether he assumes that 5% or 25% of the probable color-vision defectives did not bother to reply. From the standpoint of sex differences, the proportions of responses indicate that the ratio is 3/1 for male-female. The usual ratio of about 15/1 for the red-green type was found.

Of the twenty-four persons examined, Professor Wright has made intensive measurements on about half of them. He will report these finding and complete details on the statistical analyses in the Adolph Lomb Memorial Lecture before the Optical Society of America, 20-22 March 1952. It is anticipated that this lecture will appear in the Journal of the Optical Society of America at a later date.

EXCERPTS FROM

RESEARCH IN VISUAL PHYSIOLOGY
TECHNICAL REPORT, ONRL-7-52, ONR LONDON

Prepared by Henry A. Imus

A. VITAMINS AND VISUAL PATHWAYS

F. C. Rodger, Department of Physiology, King's College, University of Durham, Newcastle-upon-Tyne, presented a paper at the December meeting of the Physiological Society entitled, "Evidence of an interrelationship between thiamin and riboflavin and the role they play in maintaining the integrity of the visual path."

Three groups of rats were fed a high carbohydrate diet. In one, thiamin was administered at an inadequate level; in another, riboflavin was withheld; and in the third, the diet was made deficient in both these vitamins to a degree corresponding with the other two groups. Two control groups were used. One was fed on the same diet, but with a high thiamin and riboflavin supplement. The other was fed an inadequate caloric diet with full vitamin content. The thiamin-deficient rats died at the end of three months. The riboflavin-deficient rats were still alive and well at the end of eight months. The thiamin-riboflavin-deficient rats were killed at the end of six months because they showed signs of incoordination and exhibited a marked bradycardia.

Histological examination of the visual pathways from the retina to the lateral geniculate body using various techniques, revealed only slight signs of degeneration in the thiamin-deficient rats, none in the riboflavin-deficient, and gross signs in the thiamin-riboflavin-deficient. It is presumed that the last group were suffering from a severe thiamine deficiency. For this reason and because the riboflavin-deficient rats had normal visual pathways, it is assumed that the gross changes produced in the thiamin-riboflavin-deficient animals were due to the long-continued deficiency in thiamin. It is concluded that the integrity of the visual path can be affected when the thiamin intake is inadequate and a high carbohydrate diet is being fed.

B. SUMMATION IN THE HUMAN RETINA

At the December meeting of the Physiological Society, M. H. Pirenne, Physiology Department, Marischal College, Aberdeen, presented a joint paper by E. J. Denton and himself on the subject, "Spatial summation at the absolute threshold of peripheral vision."

Pirenne and Denton have been able to confirm the results of Hecht, Schlaer, and Pirenne (1942) in the measurement of the absolute threshold of peripheral vision in the dark-adapted human eye. Using a visual photometric comparison of two fields through a color filter (Ilford 604, dominant wavelength 518 millimicrons), for a target subtending an angle of ten minutes placed either 20^{o} or 7^{o} from the fovea and exposed for 2.6 microseconds, the average value of the absolute threshold (0.60 frequency of seeing) correspond at the cornea to approximately 100 quanta. When the centers of two test fields, each ten minutes of arc in diameter, were placed one-half degree apart either at 20^{o} or 7^{o} from the fovea and exposed for the same length of time (2.6 microseconds), there was evidence of partial physiological summation. When the centers of the test fields were separated by as much as 3 $1/2^{o}$, there was no evidence of summation. Pirenne and Denton conclude that the periphery of the human retina contains functional units at least $1/2^{o}$ but less than 3 $1/2^{o}$ in diameter. Partial summation may occur within these functional units, but there seems to be neither summation nor inhibition between different units under the conditions of these experiments. The results obtained differ from those obtained by van der Velden and Bouman who claim that independent fields ten minutes in diameter need only 2 quanta for excitation.

C. RETINAL PIGMENTS

At the same meeting, E. J. Denton, Department of Physiology, Marischal College, Aberdeen, presented a joint paper by M. H. Pirenne and himself under the title, "Green Rods and Retinal Sensitivity."

In the fresh retinae of dark-adapted Xenopus laevis, both red-colored and green-colored rods are found. The ratio of red-colored to green-colored rods is 30:1, the same ratio which is found in the retinae of frogs.

Denton and Pirenne suggest that the differential absorption of retinal extracts may explain the discrepancy between the human, cat and frog scotopic sensitivity curves. It is probable that the green-colored pigment is extracted along with the red. Its presence will have little effect upon the absorption curve of the extract around the peak of absorption of the red pigment. At the red end of the spectrum, where the red pigment absorbs very little light, the green pigment present may significantly affect the absorption curve.

They recommend that the presence of this green pigment in the retinae of frogs should be taken into consideration when making accurate comparisons between visibility curves and the absorption curve of visual purple of the frog. They suggest that measurements of both spectral sensitivity and the absorption curve of visual purple of salamander, which has only red-colored rods, would resolve the uncertainty.

ABSTRACTS

320. Appraisal of Development Models of Sixty-Inch Vertical Plotting Boards
Garner and Sleight
Special Devices Center, Office of Naval Research
The Johns Hopkins University, 6 pp., 20 January 1949 (R)

"Recommendations. As a result of the tests and general appraisal made at Systems Research Laboratory, the following recommendations are made.

a. A new design for the grid overlay should be used. Specifications and a sketch of the design proposed by this Laboratory are included in Appendix A.

b. Two rules should be provided for plotting on the back of the boards. These rules should be made of a translucent material, and should be marked off in miles of range. They should be anchored to the center of the plotting board and allowed to swing freely. If this recommendation is put into practice, then the outside range ring on the display should be marked off in one-degree steps, so that the plotter is not required to make a mental estimate of either bearing or range.

c. Ultraviolet lighting should be provided for the edge lighting, with fluorescent markings for the grid overlay. Likewise, a fluorescent grease pencil should be used."

321. Visibility on Radar Scopes
Stanley B. Williams
Psychological Laboratory, the Johns Hopkins University
Special Devices Center, Office of Naval Research
49 pp., 15 February 1949 (0)

"The general design of cathode-ray tubes is discussed in relation to the visual requirements of a human observer, with the chief emphasis on intensity modulated scopes of the type used in search radar. Radar scopes are rather poor as viewing screens anyway, because they flicker and fluctuate in such a way as to make them difficult to maintain at optimal brightness. Even operated optimally, they fall short of ideal visual requirements. Improvements to date have been notable but they have not been sufficient for two reasons: (1) there is a genuine lack of properly coordinated knowledge of the visual requirements themselves, and (2) the luminous output of electronic excitation of phosphor screens is not accurately predictable. Nevertheless, workers in both visual science and radar engineering have recently made significant advances as a result of direct visibility tests of various scopes. A major line of research is the investigation of the radar parameters which significantly determine visibility. Most of the research work in this field has been reviewed with the aim of highlighting the major problems and disclosing areas of ignorance. The major variables in visual detection are: the brightness and uniformity of the viewing screen; the contrast, shape and size of the pip to be seen; the methods of visual search used by the observer. Many of these depend upon the electrical parameters of the radar pulsing and receiving system. The functions relating the visual to the electrical variables are only partly known today but those that are known are briefly described."

322. Accuracy of Aligning the Movable Range Marker With Blips on the Plan Position Indicator
J. W. Gebhard
Special Devices Center, Office of Naval Research
Systems Research Field Laboratory and Psychological Laboratory, The Johns Hopkins University, 53 pp.
1 August 1948 (R)

"Four experiments were performed to determine the accuracy of aligning the movable range marker on the rotating sweep of the PPI with blips on a 20-mile sweep. The procedure consisted of mixing target simulator and range marker video and displaying the combined signals on the experimental PPI's and the VF precision indicators used for making the measurements. The task of the PPI operator was to align his marker as accurately as possible with the center of the blip. The VF operator then measured the degree and direction of the discrepancy between target and marker on the B-scope. These errors, expressed in yards, were the data used for describing alignment accuracy.

"The first experiments measured the accuracy of range marker-blip alignment on a VJ (12-inch) display using targets 120, 250, and 500 yards in thickness. The average error in bisecting blips was about 30 yards. Target thickness made no significant difference in accuracy. Short range targets (under 20,000 yards) were found more accurately bisected than long (20,000 to 40,000 yards).

"The second experiment measured the accuracy of the range marker-blip alignment on two VJ displays using three positions on the CRT for sharp focus of the sweep; 2,000 yards, 20,000 yards and 39,800 yards. Average error was about 30 yards. Normal adjustment in scope focus had no significant effect on alighment accuracy. Targets under 20,000 yards of range were more accurately bisected than those from 20,000 to 40,000 yards. Bearing had no influence on accuracy of performance.

"The third experiment measured the accuracy of range marker-blip alignment on a VJ, a TDT (7-inch) and a BRI (5-inch) display, using blips whose arc lengths were held to a constant per cent of maximum range. Three lengths of arc were tested: 3.5%, 17.5%, and 41.9% of range. Average error for all equipments and conditions tested was about 42 yards. Equipments showed no significant differences when all conditions were taken together. Short arc length blips were more accurately bisected than long. Short range targets (under 20,000 yards) yielded smaller errors than long range (20,000 to 40,000 yards). There was a suggestion in the data that it made a difference which target range was used with which equipment and which range was used with which arc length. Neither bearing nor radius of target curvature had an influence on accuracy of performance.

"The fourth experiment measured the accuracy of the range marker-blip alignment on a VJ and a VH (5-inch) display. Two conditions of target arc length were used; the 3.5% and 41.9% settings of the third experiment. The two lengths of arc were paired with each of three ranges: 5,000, 21,000, and 37,500 yards. Average error was about 34 yards. There was no difference between accuracy obtained with the VJ and with the VH displays. Short arc lengths were more accurately bisected than long on the short ranges tested; on the long ranges, arc length had no effect on accuracy.

"In the first three experiments operator differences were significant. In the fourth experiment they were not. Since a number of the same operators served in all experiments this may have been due to practice.

"A constant error was found in the last three experiments. Operators tended to align the marker at a range about 10 yards short of the center of the target.

"These experiments set a value for the accuracy of the psychophysical performance which is the basis for the use of one kind of range strobe. The order of accuracy with which radarmen can adjust the movable range marker to a target suggests that PPI equipments furnished with stable, linear ranging circuits and more finely counters could be read much more accurately than is now the case."

323. Simulated Display of Bearing and Range in Rectangular Coordinates
Gebhard, J. W., J. L. Barber, and R. M. Halsey
Psychological Laboratory, The Johns Hopkins University, Technical Report - SDC 166-1-81, 12 pp., 1 May 1949 (R)

"Several experiments were conducted to determine the speed and accuracy with which target position can be read from an experimental display of radar bearing and range information in rectangular coordinates in which 360 degrees of bearing were given on the x-axis and 40,000 yards of range were shown on the y-axis. A rectangular scope, produced by modifying a VD radar indicator, was first compared with a PPI with respect to accuracy of aligning a movable range marker with blips. The rectangular display was found to produce smaller alignment errors than the PPI, and to be free from the effect, present in PPI's, of greater error with longer ranges. The factor of target length had no effect on accuracy for the experimental display whereas on the PPI are length interacts strongly with target range in determining alignment error.

"Several bearing grids were tested on a simulated rectangular display for the purpose of selecting the most suitable design. Bearing scales marked in intervals of 20 degrees were found superior to those marked in intervals of 30 degrees as measured by speed of reading and bearing error when visual estimations of target position were made. Size of display had no effect on either speed or accuracy, nor did different starting points of the bearing scale.

"It is concluded that a rectangular display is as efficient as, and in some respects superior to, a PPI for estimating target position. Its adaptability for displaying information for tactical evaluation is questionable due to the presence of distortion."

324. San Diego County Fair Vision Survey. A Study of Visual Skills: Their Distributions and Interrelations
M. Lichtenstein
U. S. Navy Electronics Laboratory, San Diego, Calif. NE121301, Report 215, 44 pp. 29 December, 1950 (0)

"The results were analyzed with two major objectives in mind: (1) to survey an essentially random population for distribution of capacities as measured by the Ortho-Rater, with separate consideration of males in the military age group; (2) to investigate relations among visual parameters, as a possible contribution to the theory of visual mechanism. Because of the detailed nature of the data, the results have been discussed in context as they were presented. The main conclusions are recapitulated below.

1. Depth scores, and to a lesser extent, far vertical phorias, varied significantly from examiner to examiner. Other measures did not.
2. Depth, phorias, and an interaction of near vertical and near lateral phoria account for significant portions of the variance of binocular acuity.
3. Positive correlations exist between near and far vertical phorias and between near and far lateral phorias. No correlations between vertical and lateral phorias were found.

4. Vertical phorias, but not lateral, are positively correlated with interocular acuity differences.
5. Binocular acuity is maximal when monocular acuities are equal.
6. Extreme phorias are accompanied by reduced depth perception, and, to a lesser extent, reduced color vision.
7. Depth perception decreases as interocular acuity differences increase.
8. Provided acuity is good, poor stereoscopic depth perception can be improved by training.
9. Acuity is a large factor in Ortho-Rater color scores.
10. Distribution of near acuity for those who did not wear their near-vision glasses was bimodal. Those in the minor mode had poor acuity, while the acuity of the remainder was very good.
11. All other distributions of near and far acuity for all ages combined were rather sharply peaked and somewhat skewed toward poorer acuity.
12. Acuity varies in a curvilinear manner with age. Maximum acuity is attained in the 20-to-29 year old group.
13. Males have better acuity than females.
14. The 75th percentile binocular far acuity of those who wear distance glasses does not decline with age. Otherwise, all 75th and 25th percentiles (for near and far vision of those who do and those who do not wear glasses) parallel the mean acuity-age variation.
15. Acuities, in ten-year age groups, are more nearly normally distributed then distributions for all ages combined.
16. Monocular acuities vary with age in the same manner as do binocular, at a slightly poorer level.
17. Mean acuity of the left eye was better than that of the right.
18. In early years, the acuity of those who do not wear glasses exceeds the corrected acuity of those who do. This condition is reversed in the higher age groups.
19. People under 30 years of age who neglected to wear their near-vision glasses performed better on the near-vision acuity test than those who did wear their near-vision glasses.
20. Near acuity is superior to far acuity for people under 40 years of age. For those over 40 who do not wear glasses, the situation is reversed and far acuity exceeds near. For those above 40 who do wear glasses, near and far acuities are about equal.
21. Curves of near versus far, and left-eye versus right-eye acuity exhibit central tendencies. If, for example, a person's near vision is poor, his far vision is likely to be better, and vice-versa. The same applies to the left eye-right eye comparisons.
22. Acuities of both eyes are equal, within the limits of Ortho-Rater test step widths, in approximately 27 per cent of the cases.
23. Vertical-phoria distributions were sharply peaked. Distributions of all groups (those who wear glasses, do not wear them, neglected to wear them, males, females) were essentially alike.
24. Near vertical-phoria distributions were displaced, with respect to far vertical, in the direction of left hyperphoria.
25. Lateral phorias, with the exception of near lateral phoria of those who wear near-vision glasses, show little inter-group differences. Almost 15 per cent of the latter group evidenced the most extreme exophoria measured by the test. Those who neglected to wear their near-vision glasses did not show this effect.
26. Phorias were, in general, most prevalent in the highest age groups.
27. Near phorias were more prevalent in the population than far phorias.
28. Corrected color-vision scores did not decline with age.
29. Depth perception declined with age. In spite of the acuity-depth positive linear correlation, people under 20 who had lower mean acuity than those int the 20-to-29 group had better stereoscopic depth perception.

30. The percentage of people wearing glasses increases with age. This increase is sharpest after 30 years of age. Near-vision glasses are worn more frequently than far; a greater proportion of women than men wear glasses.
31. Binocular far acuity for males of military age is 1. 36 minutes of minimum visual angle at the 5th percentile, 0. 76 minute at the 95th. Visual-angle near acuity at the same percentiles is 1. 09 minutes and 0. 77 minute, respectively.
32. Not more than 12 per cent of the military-age group have seriously deviating phorias of any type.
33. Depth perception scores of the group had a rectangular distribution.

325. Perspective Analysis of the Proposed Alpa Approach Light System
Roy E. Warren
Technical Development Report No. 133
Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis Indiana, 15 pp. January 1951 (0)

"This report is a supplement to Technical Development Report No. 96, "Perspective Analysis of Approach Light Patters," and covers the perspective analysis of the ALPA approach light system. It includes sketches of the perspective patterns as seen from several different viewing positions as well as a discussion of the effectiveness of guidance furnished by the system."

326. Flight by Periscope
Stanley N. Roscoe,
Department of Psychology, University of Illinois,
University of Illinois Bulletin, Vol. 48, No. 55
March 1951 (0)

"The purpose of this study was to evaluate a realistic pictorial attitude display in standard instrument flight tasks and to determine the influence upon pilot performance of two independent variables in the design of pictorial displays.

"Eleven pilots flew a standard instrument flight pattern with a Cessna T-50 airplane in nine experimental conditions using a "periscope" as a pictorial attitude display and in two control conditions. The nine experimental conditions samples two variables in the design of pictorial attitude displays: the size of the display (screen size) and the magnification of the image (the width of the horizontal and vertical outside angles included in an image of a given size).

"In the first control conditions, the pilots flew with unrestricted contact visibility, and, in the second, with no outside visibility or cockpit attitude display. A new technique was used to evaluate pilot performance in standard instrument flight tasks. The results of the experiment, as evaluated by this technique, were as follows:

1. Pilot performance improved with increases in the size of the attitude displays; equal increments in screen size resulted in diminishing increments in performance, within the limits tested.

2. Pilot performance improved with increases in the outside angles included in a periscope image of a given size; equal increments in horizontal and vertical outside visibility resulted in increasing increments in performance, within the limits tested.

3. Pilot performance in the nine experimental conditions showed no significant interaction between screen size and image magnification.

4. Pilot performance with an eight-inch square attitude display, the largest tested, was not significantly different from that achieved with contact visibility.

5. Pilot performance with a two-inch square attitude display, the smallest tested, was significantly worse than performance with contact visibility but significantly better than performance with no cockpit attitude display or outside visibility.

The following hypotheses were suggested by the experimental findings:

1. Within the range of screen sizes tested, pilot performance in standard instrument flight tasks bears a linear relationship to the reciprocal of the horizontal, or vertical, dimension of a square periscope screen.

2. Within the range of magnification tested, pilot performance in standard instrument flight tasks bears a linear relationship to the square of the angle of outside visibility included in a periscopic image of a given size."

327. The Subitizing and Counting of Visually Presented Fields of Dots
Jensen, E. M., Reese, E. P., T. W. Reese
Special Devices Center, Office of Naval Research
Psychophysical Research Unit, Department of Psychology and Education, Mount Holyoke College, 29 pp.
1 October 1950 (0)

"We projected fields of dots, ranging in number from 1 to 30, on a screen. Our S's were instructed to report the number of these dots, and they were given all the time they needed to do so. From our data, analyzed in terms of accuracy of report and the time between the stimulus and the report, we make the following conclusions:

1. As might be expected, our S's reports of 1 to 30 dots were on the average highly accurate.

2. The first derivative of the function relating report-time and number of dots presented is discontinuous at about 6 stimulus-dots. Kaufman et al., who presented dots tachistoscopically for 1/5-second, found a discontinuity in a similar function at approximately the same point.

3. The function relating report-time and number of dots presented has a characteristic shape. This is most clearly seen when the data are transformed by a reciprocal equation and plotted on semilogarithmic coordinates. On these coordinates the first 5 or 6 points fall along a straight line which has a high negative slope. The remaining points fall along a shallow, decelerating curve.

4. Our S's subitized up to 5 or 6 dots and counted the rest. They subitized up to 5 or 6 dots even though accuracy was stressed, and they were given time enough to count."

328. The Discrimination of Visual Number
Kaufman, E. L., M. W. Lord, T. W. Reese, J. Volkmann
Systems Research, The Johns Hopkins University,
Special Devices Center, Office of Naval Research
27 pp. 1 October 1949 (0)

"Our S's received brief, simultaneous, visual presentations of randomly arranged fields of dots. They were instructed to report the number of these dots. Some S's were further instructed for maximum accuracy of report, and others for maximum speed. The actual number of stimulus-dots varied between 1 and 210.

"The results of the experiment are in terms of the percentage error and the variability of the reported number, the time between the stimulus and the report, and the confidence with which the report was given. Analysis of the results, including analysis by graphical rectification, leads us to the following conclusions:

1. The functional relations between time and stimulus-number, and confidence and stimulus-number are discontinuous in slope. Taves has already drawn the inference that there are two mechanisms for the discrimination of visual numerousness. That inference is fully supported by our results.

2. The functions for both time and confidence are discontinuous in slope at nearly the same point. This point is close to 6 stimulus-dots.

3. The instructions (a) for speed and for accuracy yield functions that are similar in shape; (b) for speed produce more speed; (c) for accuracy produce slightly more accuracy and less variability.

4. The time between stimulation and report increases regularly from 1 to 5 or 6 stimulus-dots. From parallel evidence, Saltzman and Garner have argued that if the term span of apprehension is defined as the immediate cognition of number, there is no such thing. We agree!

5. On operational grounds, useful distinctions can be drawn between subitizing (a new term), estimating, and counting.

6. On the average, subitizing is a considerably more accurate, more rapid, and more confident process than estimating."

329. Visual Acuity at Scotopic Levels of Illumination
Morris, Ailene and Forrest L. Dimmick
Medical Research Laboratory, U. S. Naval Submarine Base, New London. Report No. 162, Vol. 9, pp. 157-183
4 December 1950 (0)

"Measurements of visual acuity have been made at light levels that cover the range of scotopic vision.

"A checkerboard-type target was used in which each side of the checkerboard area subtended a visual angle of 9^{o}. Its center lay 10^{o} from the fixation point. Individual checkers ranged in angular subtense from 8 minutes to 3 degrees. Targets were presented in four positions, that is, with the checkerboard area up, down, right, and left.

"By the psychophysical method of constant stimuli, acuity thresholds were obtained for six observers at eight light levels between 3.7 log uuL and 6.7 log uuL. The 50% limens

plotted in units of reciprocal visual angle against log brightness showed acuity increasing in a straight line function whose average equation is V = .033 log B - .09. At the scotopic level brightness difference is the principal factor.

"Measurements with an infra-red pupillometer showed that pupil size changed with light level in this range and was correlated with individual differences in acuity.

"Six log uuL has been confirmed as the upper limit of brightness for which scotopic acuity is uncontaminated by photopic factors."

330. <u>Inspection Goggle for Checking Visible Spectral Quality of Lighting for Dark Adaptation</u>
LCDR Dean Farnsworth
Medical Research Laboratory, U. S. Naval Submarine Base, New London, Report No. 170, Vol. 10, pp. 1-17 15 March 1951 (0)

"An inspection goggle is described with which a visual check can be made by an eye of normal color vision of the spectral composition of red light to determine its conformance to Naval Specifications for dark adaptation. Observed results on sample glasses are compared with calculated results."

331 <u>A Landing Display for Use With a Contact Flight Simulator</u>
John M. Bell
Special Devices Center, Port Washington, Office of Naval Research, Technical Report SDC 71-16-8
18 pp. March 1951 (0)

"The usefulness of a synthetic flight trainer depends in a large part upon the number and variety of maneuvers that can be taught in it. A trainer that can be used to teach instrument flying, for example, is not as useful as one that can be used to teach both instrument and contact flying. The use of existing contact flight trainers is usually restricted to air work maneuvers because of the lack of adequate simulation of ground-derived cues. One of the most difficult maneuvers to learn in a contact flying syllabus, in terms of the time spent on it, is the approach to a landing. If this maneuver could be taught successfully in a synthetic trainer, the usefulness of the trainer would be greatly extended.

"In order to teach contact landings using a synthetic flight trainer such as the 1-CA-2 SNJ Link, some devise must be designed and constructed that will present sufficient visual cues for a pilot to perform a satisfactory landing. A previous attempt to do this has been reported recently by this laboratory. In that study a tilting blackboard and screen were so arranged in front of a School Link trainer that the illusion of an approach and landing could be achieved in a crude fashion. The results of the study indicated that some transfer of training occurred. Students instructed with the device made fewer errors when learning to land a real aircraft than did students who were not so instructed. The difference between the two groups was significant:

"The cues presented by the blackboard and screen represented an attempt to show the runway in perspective and in proper relation to the horizon, these functions being varied as the approach progressed. It was known at the time that the presentation was not geometrically correct. It was not known at the time, nor is it known now, that these perspective cues are the cues a pilot actually uses when performing an approach and landing. Nevertheless, the encouraging results of the first study have prompted the present analysis. It is hoped that

with a geometrically correct display, which is now possible as a result of this analysis, results of practical importance will be obtained.

"This report presents a mathematical analysis of the visual perspective cues that occur during an approach to a landing and the application of this theory to the design of an actual training device."

332. A Study of the Requirements for Letters, Numbers and Markings to be Used on Trans-Illuminated Aircraft Control Panels. Part 3 - The Effect of Stroke-Width and Form Upon the Legibility of Numerals.
Fred R. Brown
U. S. Navy, Naval Air Material Center, U. S. Naval Base, Philadelphia, Pa. 32 pp. 29 December 1948

"This is Part 3 of a study of the legibility characteristics of markings used on trans-illuminated consoles in aircraft cockpits. Two forms of numerals, those devised by Berger and those of AND 10400 have been used for legibility tests in several stroke-widths. Tests have been conducted under two general conditions: Floodlighting simulating daylight and the red trans-illumination used in night operation.

"The results indicate a general preference for the Berger form. Especially noteworthy is the much higher legibility of the Berger "4". The remainder of the numerals have only slight differences in legibility in the two forms, except the "9" which under daylight is distinctly better in the AN form.

"Of the individual numerals, the "7", "1" and Berger "4" are the most recognizable. The least recognizable are the "8", "0" and "3".

"The stroke-width data indicate that a stroke-width to height ratio of 1:8 is optimal when all the conditions of use are considered, especially the low trans-illumination levels commended for use in aircraft cockpits to facilitate dark adaptation. Under trans-illumination, numerals with stroke-width to height ratios of 1:7 and 1:8.6 are nearly as those with a ratio of 1:8.

"A series of digits has been designed incorporating the characteristics of the numerals tested which appear to improve digit legibility. Validation studies for this numeral series will be conducted as a subsequent part of this project."

333. The Perception of the Vertical: XI The Visual Vertical Under Conflicting Visual and Acceleratory Factors
Wing, Cliff W. and George E. Passey
U. S. Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida, Report No. 20, 8 pp.
15 November 1950 (0)

"Four S's made adjustments of the visual vertical in both presence and absence of a visual frame of reference under varying resultant acceleratory forces produced in a human centrifuge.

"In the absence of a visual frame of reference the subjectively accepted vertical to which S adjusted a target was aligned with the resultant acceleratory force. The adjustment was made whether or not the resultant force was aligned with S's body axis or acted at some angle to it.

"In the presence of a visual frame of reference which was in alignment with the resultant force S adjusted the visual vertical to a position which placed the target in alignment with the resultant force and the main lines of the visual framework.

"In the presence of a visual frame of reference which is aligned with S's body axis and a resultant force which acts at some angle with S's body axis and the visual frame of reference S adjusts the visual vertical to a position of compromise. Neither visual or postural cues are accepted to the exclusion of the other. With increased intensity of the postural cues furnished by an acceleratory force the visual vertical is located relatively nearer to the vertical determined by the resultant force.

"On the basis of the results of this experiment we find judgment of the visual vertical to be a function of both visual and postural factors."

334. An Aspect of Searching With Binoculars
W. E. Hick
Medical Research Council, The Psychological Laboratory, Cambridge. 5 pp. September, 1950
(0)

"A comparison was made of the efficiency of searching for a small object with binoculars using both eyes, with the efficiency, in the same conditions, using one eye. The question has reference to a proposed modification to binoculars for the purpose of facilitating the systematic searching of the sky for aircraft.

"The principal outcome was that, in the conditions employed, one eye (the better eye, whichever it happened to be) was as efficient as both eyes. From this point of view, therefore, there is nothing against further consideration of the proposal which is to deflect the line of sight of one ocular down to the horizon, in order to provide a datum in the plane of elevation."

335. Some Design Factors Affecting the Speed of Identification of Range Rings on Polar Coordinate Displays
U. S. Navy, Office of Naval Research, Special Devices Center, Port Washington. Technical Report SDC 166-1-95 25 pp.
10 August 1949 (R)

"Purpose of experiments. Before an observer can make a visual interpolation to estimate range on a polar coordinate display, he must determine the range of the nearest range ring. The experiments reported here were designed to investigate some of the factors affecting the speed with which an observer can identify the range of a particular range ring on a polar coordinate display. Specifically, we studied the effect on the speed of identifying range rings of (1) the total number of rings and (2) the patterning of the rings.

"Procedures. Two different procedures were used. In the first experiment, a pattern of range rings was flashed on a projection screen, and one range ring on each display projected was marked with a large "X". The observer's task was to identify the range of the marked ring as rapidly as possible; the time required for each identification was measured. In the second experiment, the observer was given a deck of 32 cards and he was required to deal the cards off the deck and identify the one range ring on each card that was marked with an "X". For each of 13 decks of cards a different range-ring pattern was used. The score obtained was the time required to identify all 32 marked range rings in a complete deck of cards. In this second experiment, observers' errors were recorded and analyzed."

336. The Effects of Size and Brightness on the Speed of Identifying Number of Range Rings
Saltzman, I. J., and W. R. Garner
Special Devices Center, Office of Naval Research
The Johns Hopkins University, Psychological Laboratory
13 pp. 20 January 1949 (0)

"Introduction. In reading ranges from a polar coordinate display, the observer must first determine the range of the range ring nearest the target, and then make a visual interpolation for a precise estimation of range. One of the factors affecting how fast an observer can identify a particular range ring is the speed with which he can determine the total number of rings. These experiments were designed to investigate the effects of display size (visual angle) and brightness on the speed of reporting the total number of range rings.

"Procedures. Various numbers of range rings were projected onto a screen, and the observer was required to call out the total number of rings as soon as he had decided what the number was. Accuracy was stressed, and the total time required for the correct identification was measured. Visual angles between one degree -- 10 minutes and 90 degrees, and brightness levels between 0.05 and 55 apparent foot candles were used."

337. The Perception of the Vertical: XII The Point of Shift From Visual to Postural Frames of Reference
Ray, James T., and J. I. Niven
U. S. Naval School of Aviation Medicine
Naval Air Station, Pensacola, Florida
7 pp. 8 February 1951 (0)

"Summary. The present report is concerned with investigation of the relative importance of visual and postural factors in the judgment of the vertical. The general hypothesis is that the individual relies on two frames of reference, one visual and the other postural, and that in the event of marked conflict between them postural cues will dominate, and the individual prefers to rely on his 'feeling.'"

"Four subjects were used. Each was placed in a chair and, with eyes closed, was tilted right or left and then brought to rest at a tilt of 45° right, 0°, or 45° left in a random order. As this was done, a vertical pointer was displaced. The subject was required to return the pointer to the vertical position by adjustment of the chair. This operation simultaneously moved the pointer. This adjustment was made on the basis of visual cues."

"The subject was then required to make a further adjustment to bring the chair to what he felt was vertical, if he felt that the postural cues did not coincide with the alignment made visually to the target. However, a systematic error could be experimentally introduced into the visual cues by offsetting the selsyn-controlled pointer from its normal position while the subject was being tilted. For each position of the chair, the target was offset by 12, 10, 8, 6, 4, 2 degrees to the right or left or by 0° (i.e. was not altered) in a random order. In all, each subject made 195 judgments each of the visual and postural vertical."

"The chief findings were:

1. The postural vertical judgment did not differ significantly from the true gravitational vertical under any condition.

2. The judged visual vertical, however, deviated increasingly from the true gravitational vertical as target displacement from its true position was increased. Under

conditions of no chair tilt or tilt opposite to the target, the magnitude of the deviation was equal to target offset. When chair tilt was in the same direction, the magnitude of the deviation increased with target offset. These generalizations hold for all cases only beyond a critical area varying from 2 to 6 degrees from the true gravitational vertical. This critical area is interpreted as a region of conflict between visual and postural cues, in which the individual prefers to rely on his 'feeling'.

3. The constant error, i. e., systematic error of judgment due to any cause, of the postural or visual vertical judgments was not influenced significantly by target offset.

4. Average error, reflecting variability of judgment, increased with target offset and significantly more for the visual than for the postural judgment."

"The findings are interpreted as supporting the dominance of postural cues in the perception of the gravitational vertical. Moreover, postural factors were found to influence the judgment of the visual vertical, although the converse, the modification of the postural vertical by visual factors, was not demonstrated. Thus in any situation in which an individual, such as a pilot, is subjected to this type of conflict, reliance tends to be placed on postural rather than visual cues and disorientation or misinterpretation of instruments may result."

338. Speed Anticipation and Course Anticipation in Tracking
E. C. Poulton
Medical Research Council. Applied Psychology Research Unit. The Psychological Laboratory, Cambridge, 12 pp. September, 1950 (0)

"Summary. In order to study separately the two kinds of perceptual anticipation in tracking, speed anticipation and course anticipation, two different experimental arrangements were used. In one the subject had to predict the position of a pointer moving in harmonic motion, at a given time ahead. In the other the subject had to keep a pointer in line with a second pointer moving in harmonic motion, when he only received intermittent glimpses of the display.

"It was found that it was not the length of time ahead, but what happened during that time, which determined the accuracy of perceptual anticipation at different distances in the future.

"The importance of speed anticipation in "blackout" tracking was demonstrated experimentally by reducing the length of the glimpses of the display, so that the subject could see only the successive positions of the "stimulus" pointer at fixed intervals of time, not its speed in these positions. His performance deteriorated accordingly."

339. The Speed and Accuracy of Plotting with a Simulated PPI Marker Strobe. Part II: The Relation of Speed to Accuracy.
Medical Research Council, The Psychological Laboratory, Downing Place, Cambridge
3 pp. March, 1950 (0)

"Summary

1. A radar P. I. I. display is simulated by the optical projection of patterns of "echoes" and a marker strobe on to a ground-glass screen. The operator has a control handle by

means of which he places the strobe on each echo in turn as quickly and as accurately as possible, making a movement each time which records the exact position of the strobe.

2. The present study deals with the relation of speed to accuracy of plotting.

3. It was found that the relation between speed and accuracy for the range investigated was a logarithmic one, and can be represented by the equation

$$\log E = 0.34 - 0.35 \log T,$$

where E = envelope error in mm., T = mean time per plot in seconds."

340. An Aspect of Searching with Binoculars.
W. E. Hick
Medical Research Council, The Psychological Laboratory, Cambridge, 5 pp.
September, 1950 (0)

"Summary. A comparison was made of the efficiency of searching for a small object with binoculars using both eyes, with the efficiency, in the same conditions, using one eye. The question has reference to a proposed modification to binoculars for the purpose of facilitating the systematic searching of the sky for aircraft.

"The principal outcome was that, in the conditions employed, one eye (the better eye, whichever it happened to be) was as efficient as both eyes. From this point of view, therefore, there is nothing against further consideration of the proposal, which is to deflect the line of sight of one ocular down to the horizon, in order to provide a datum in the plane of elevation."

341. The Parameters of Scotopic Sensitivity: (1) The Effect of Size.
Jo Ann Smith and Forrest L. Dimmick
Medical Research Laboratory, U. S. Naval Submarine Base, New London. Report No. 174, Vol. 10, pp. 56-75 20 June 1951. (0)

"The scotopic sensitivity of the dark adapted eye was determined for stimuli of variable size and constant brightness, as the first part of a fuller investigation of the parameters of night vision. The visual field was explored at points having various degrees of ecentricity in each of four quadrants, all chosen to yield a sample of total sensitivity.

"Using the 50% limens in terms of the angular subtense of the stimuli as the measure of sensitivity, a complete picture of the sensitivity gradients of the eye was found throughout the visual field. Further studies will deal with the other parameters of sensitivity and their interrelationships."

342. An Ophthalmological Study of Visual Acuity Under Dim Illumination
Cornelia Pratt and Forrest L. Dimmick
Medical Research Laboratory, U. S. Naval Submarine Base, New London. Report No. 173, Vol. 10, pp. 42-55 6 June 1951 (0)

"An experiment investigating the relationship between refractive error and lost of acuity under low illumination was performed by Dr. Franklyn D. Burger. Snellen acuity scores at 24 light levels from 2 foot candles down to .0027 foot candles were obtained from each eye of 558 subjects. The subjects were also refracted for best acuity.

"The highest acuity scores throughout were made by +.75 diopter hyperopes. Absolute differences in acuity due to refractive error diminish with lowered illumination to a point where they have little significance. The results indicate, however, that for non-astigmatic subjects with refractive errors between +1.00 and -.50 diopters, the proportionate change in acuity with illumination is not influenced by refractive error."

343. A Study of the Requirements for Letters, Numbers and Markings to be Used on Trans-Illuminated Aircraft Control Panels - Part 6 - A Survey of Pilot Preferences for Special Attention Plate Markings.
Reported by: Lloyd M. Crumley and Marion P. Willis
Aeronautical Medical Equipment Laboratory Naval Air Experimental Station, Naval Air Material Center, Philadelphia, Penna. - Report TED No. NAM EL-609 Part 6. 18 September 1951 (0)

"An opinion survey has been conducted among a group of naval pilots and other flying personnel familiar with flight problems to determine their preference among twelve alternative designs for surrounds suitable for use with trans-illuminated special attention plates in aircraft cockpits.

"The results of the survey indicate that a satisfactory special attention plate design employs a minimal light flux and configuration of lines in such a manner that the area surrounding the panel attracts the pilot's attention when it falls in his field of vision, isolates the legend from the immediate surround and from the balance of the control panel, and directs the pilot's attention from the attracting surround to the legend.

"It was indicated that the elements of an unsatisfactory panel were mainly excessive light flux, configurations and devices that tend to direct the pilot's attention away from the legend, and surrounding material that encroaches on and rendors the legend less legible.

"Since no satisfactory simple method of surround markings was found suitable for both day floodlighting and night trans-illumination use, a panel design is recommended which gives a somewhat different appearance by day than by night."

344. The Effects of Auditory-Vestibular Nerve Pathology on Space Perception
Reported by: Cecil W. Mann, Chairman Psychology Dept., Tulane University - The Bureau of Medicine and Surgery Project No. NM 001 063.01.22, 15 August 1951 (0)

"The results of this series of tests indicate that paralysis of the auditory-vestibular

nerve produces reduced precision of judgment of the postural vertical and absence of adaptation to postural inclination; increased error of judgment of the visual vertical from positions of postural tilt and in the direction of the Aubert effect; and reduced nystagmus and oculogyral effects. The absence of the Muller effect and the increase in the Aubert effect over that found in intact adults appear to be evidence for the compensatory function of the vestibular mechanism when the head or the body are laterally inclined. This supports the hypothesis that the perception of verticality in intact individuals is determined by the joint reciprocal action of the visual and proprioceptive stimulus variables.

345. A Study of the Requirements for Background Lighting of Aircraft Instruments and Lucite Illuminated Consoles - Part 3 - Investigations in the Floodlighting of Trans-illuminated Cockpit Displays, (A) A Study of floodlighting trans-illuminated instrument dials, (B) A survey of pilot preferences for floodlighting levels with trans-illuminated console panels.
Reported by: David Alsher, Physicist and John Lazo, Test Engineer, Aeronautical Med. Equipment Lab., Navy Air Material Center, Philadelphia, Pa. BUAER ltr Aer-EL-63, 20772, of 12 March 1947
17 October 1951 (0)

"A study was made of the desirability of floodlighting in conjunction with trans-illumination of cockpit-type dial instruments and of control panels.

"In one phase of the present study a series of tests was conducted utilizing a special dial reader. Error scores were obtained of four selected subjects reading red trans-illuminated dial markings in a series of several brightnesses, with no floodlighting and with several levels of floodlighting. Opinions of subjects on the desirability of the various illuminating conditions were noted. Reading performances in these test situations did not improve significantly above 0.04 foot lamberts of trans-illuminating on the markings. The addition of floodlighting with trans-illumination at this level resulted in a subjectively more comfortable reading situation even though errors in reading did not show significant differences.

"In a second phase of this study, fifteen experienced pilots, while seated in a cockpit mock-up selected the combination of red trans-illumination and red floodlighting which they would prefer for night flying. From the data obtained, it is concluded that a fixed level of supplementary floodlighting should be used with any selected level of indirect lighting in the cockpit lighting installation. This floodlighting level would serve to provide the pilot with better cockpit orientation and visual comfort. In addition, two other floodlighting levels are proposed to satisfy the pilot lighting needs when trans-illumination has failed and when the pilot is not dark adapted. These three levels are recommended for the "dim", "medium", and "bright" positions of the three-position selector switch."

346. Some Data on the Influence of Attempted Interpolation On the Speed and Errors of Scale Reading
Reported by: William E. Kappauf, Princeton Univ.
United States Air Force, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio.
AF Tech. Report No. 6530
May 1951 (0)

"This report presents data which indicate the manner in which the speed and errors of scale reading are influenced by a change in reading instruction from "Read to the nearest scale mark" to "Read to the nearest tenth of a scale division". The data were obtained in a short experiment in which 20 subjects read a series of simply designed, straight scales which were graduated every unit and numbered every 10. Their general instruction was to work as rapidly as possible.

"As compared with readings taken to the nearest unit, readings which are attempted to the nearest tenth of a unit required about one and one-half seconds additional reading time, entailed about 50% more reading errors, and had a larger mean square error. The error increase applied both to gross reading errors -- and to local errors which resulted in failures to obtain readings correct to the nearest unit. Data extracted from the records of Experiment 4 of the Princeton University Laboratory series bear out these results.

"The data are interpreted to mean that the task of interpolating to tenths of divisions increases the reader's likelihood of making systematic errors. Readings to tenths would become superior only if better reading techniques, checking procedures or improved scale designs were developed which would eliminate gross errors."

347. Recognition Time for Dial-Type Numerals as a Function of Size and Brightness
Reported by: Mason N. Crook and Frances Schulze Baxter, The Inst. for Applied Experimental Psychology Tufts College - U. S. Air Force, Wright Air Dev. Center, Wright-Patterson Air Force Base, Dayton, Ohio - AF Tech. Report No. 6465
March 1951 (0)

"Recognition time as a function of digit size and brightness was determined for white dial type digits on a dark ground. The brightness range was from 0.003 to 0.1 foot-lambert. Average recognition time under the most favorable conditions tried was about 0.6 second. As size or brightness decreased, recognition of such secondary factors as individual differences, grouping of digits, and reduction in brightness contrast was relatively small when size-brightness conditions were favorable, but tended to be much larger when size-brightness conditions became difficult. So far as variables here investigated are concerned, it would be desirable to maintain operational conditions such that single digits would be recognized by the median subject within about 0.7 seconds. The necessary size-brightness combinations, however, would involve complications with space limitations and dark adaptation, so practical compromises are necessary."

348. Design of Instrument Dials for Maximum Legibility - Part V. Origin Location, Scale Break, Number Location, and Contrast Direction
Reported by: William E. Kappauf, Princeton University
United States Air Force, Wright Air Development Center,
Wright Patterson Air Force Base, Dayton, Ohio.
AF Technical Report No. 6366
May 1951 (0)

"This report deals with an investigation of the effects which origin location, scale break, number location and contrast direction have upon the speed and accuracy of dial reading. Specific errors which are examined and discussed include reversal errors and errors of plus one numbered scale division. The data are based on a total of 40,400 readings contributed by 46 subjects tested in a group testing situation.

"Within the limits of design variation studied, the results indicate that the best design for a simple dial which is to be numbered every 10 units and read quantitatively at any and all scale values, is one which has a scale break at zero, locates the zero near the bottom of the dial, and locates the numbers outside the scale. At daytime illumination levels like those used in the present experiment, it makes no difference whether the dial is of black-on-white or white-on-black design.

"Both the error of plus one numbered division (plus 10 units in the present case) and the reversal error are found to be associated with the reading habit of consulting the scale number which is nearest the pointer. The plus 10 units error is most common in the numerical scale region 0 to 9 no matter where that region appears on the dial. The reversal error is more common in the lower half of clockwise dials where the scale proceeds from right to left than in the upper half where the scale proceeds from left to right."

349. Psychophysiological Factors in Spatial Orientation
Papers presented under the auspices of the Psychophysiology Branch Office of Naval Research in cooperation with the U. S. Naval School of Aviation Medicine, U. S. Naval Air Station, Pensacola, Florida - Office of Naval Research, Dept. of the Navy, Washington, D. C. - NAVEXOS P-966
30-31 October 1950 (0)

"The Naval Research Advisory Panel for Psychophysiology sponsored a Symposium on Psychophysiological Factors in Spatial Orientation, of which this is the complete report. The report contains summaries of each of the following presentations made at the meeting:

1. Spacial Disorientation in Flight
   Capt. Ashton Graybiel, MC, USN

2. Anatomy and Physiology of the Vestibular System
   Harlow W. Ades

3. Cortical Projection of Postural Impulses
   Walter A. Mickle and Harlow W. Ades

4. Individual Differences in Mode of Space Orientation
   Herman A. Witkin

5. Factors Influencing the Perception of the Vertical
   Cecil W. Mann

6. Some Characteristics of Vestibular Eye Movements
   George R. Wendt

7. Studies to Define Quantitatively the Stimulus Required to Produce Motion Sickness
   Walter H. Johnson

8. Psychological Effects of Increased Positive Radial Acceleration
   Neil D. Warren

9. The Lag Effect Associated with Stimulation of the Semicircular Canals as Indicated by the Oculogyral Illusion
   W. Brant Clark and Capt. Ashton Graybiel, MC, USN

10. The Effect of a Change in Direction of Resultant Force on Sound Localization: The Audiogravic Illusion
    Capt. Ashton Graybiel, MC, USN and Jorma I. Niven

11. Age As a Variable in Post-Rotational Phenomena
    Frederick E. Guedry, Jr.

12. The Operating Principle of the Vestibular Mechanisms
    Robert Mayne

13. The Relation Between Visual and Postural Determinants of the Phenomenal Vertical
    James J. Gibson

14. Some Studies of Visual Perception of Motion
    William H. Ittelson

15. Summary
    Capt. Ashton Graybiel, MC, USN and Cdr, Alan Grinsted, MSC, USN"

350. The *Effect of Pointer Design and Pointer Alignment Position on the Speed and Accuracy of Reading Groups of Simulated Engine Instruments
Reported by: William J. White
United States Air Force, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio, - AF Tech. Report No. 6014
July 1951 (0)

"To determine some of the psychological factors which influence the reading of groups of engine instruments, experiments were conducted on the effect of pointer design and pointer alignment position on speed and accuracy of instrument reading. The task of the subject, in the first experiment, was to check read a panel of sixteen simulated engine instruments and indicate alignment or misalignment by a hand-held toggle switch. Five pointer modifications were studied in relation to response time and errors, with special emphasis on the latter. Results of the experiment indicate that modification of the pointer base to the extent employed in the experiment does not accomplish a satisfactory reduction of 180 degree type error.

"The second experiment required a qualitative reading of the deviation in order to make

a correction by selecting the appropriate switch and moving it in the proper direction. All switches were vertically oriented. The 9, 12, 3, and 6 o'clock positions for pointer alignment were evaluated in terms of exposure time as well as response time and error. Alignment at the 9 o'clock position was superior for qualitative reading, both for experienced pilots and pre-flight cadets.

"The subjects' task in the third experiment was to check read a panel of simulated instruments with pointer alignment at the 9, 12, 3, and 6 o'clock positions to indicate alignment or misalignment by means of a hand-held toggle switch. Evaluation of the alignment position was in terms of response time and errors. The statistical analysis of these measures did not yield any significant differences."

351. The *Use of Mathematical and Meteorological Data in Aeronautical Chart Construction
Reported by: Rolland H. Waters and Jesse Orlansky
Office of Naval Research, Washington 25, D. C.
Contract N8orn-641, Task Order 05
25 May 1951 (0)

"Problem

To describe mathematical and meteorological criteria for the selection of features to be shown on aeronautical charts.

Factual Material

1. The natural and cultural features represented on aeronautical charts provide the cues by which the navigational task is accomplished. These symbolized features must be sufficient in number and kind to enable the pilot to perform this task safely and efficiently.

2. More features are available on the ground than can be represented on the chart and still maintain the necessary legibility of the chart. This fact forces the cartographer to select the features to be shown.

3. Mathematical tables and graphs were developed from which the relation between an object's size and its angular subtense at the eye from different altitudes can be read.

4. Nomographs developed in connection with another problem were selected and their use in the prediction of object visibility from high altitudes is described.

Conclusions

1. The selection of features to be shown on aeronautical charts is a problem requiring technical information and criteria.

2. Such technical information and criteria are available in the fields of psychology, mathematics and meteorology.

3. The formulae, tables, graphs and nomographs embodied in this report present the way in which this information can be used by the cartographer in selecting features to be represented on aeronautical charts.

4. The material is presented in a theoretical and abstract manner and is illustrated by the use of contemporary charts, but its valid application to concrete problems needs to be established.

Recommendations

1. Conduct tests of the validity of the theoretical results presented by determining the visibility of natural and cultural features from different altitudes.

2. Conduct studies to determine empirically the contrast ratio values of different kinds of natural and cultural features situated in different surrounds, e. g. , the contrast ratio between a river and backgrounds formed by a desert, farm land or a forest.

352. A "Navigational Form for Cross-Country Flight
Reported by: Robert J. Cramer, Rolland H. Waters, and Jesse Orlansky
Office of Naval Research, Washington 25, D. C.
Contract N8onr-641, Task Order 05
29 May 1951 (0)

"Problem

To develop a tabular form designed to display the information necessary to meet the navigational requirements for routine cross-country flight by pilots in single-operator aircraft.

Facts

1. The navigation information necessary for a cross-country flight is composed of different types of data obtained from many different sources. These sources include charts, publications, computers, and briefings, written or oral.

2. These sources are inconvenient to carry, use and stow in the cockpit of single-operator jet aircraft.

3. Contemporary charts have no provision for recording fuel consumption, administrative and related information.

Methods of Study

1. Conferences were held with pilots to study the general problems of high-speed, high-altitude navigation and to analyze the nature and use of the navigational tools, instruments, aids and techniques at present available.

2. A preliminary form was constructed (on the basis of the above analyses) and its specific content and structure was examined in additional conferences with jet pilots.

3. Revised forms were constructed incorporating the suggestions and criticisms arising from the conferences.

Conclusions

1. The specific conclusions relative to the content and structure of a satisfactory form are embodied in the forms included as a part of this report.

2. The proposed form constitutes a more adequate tool of navigation than any one navigational aid now available.

3. The form is constructed so that it can be adapted to meet the demands of individual pilots.

4. The size of the form fulfills the requirements imposed by the limited space available for navigational aids in the cockpits of high-altitude, single-operator aircraft.

5. The adequacy of this form can be established only by subjecting it to flight checks.

6. It is possible that such a form can be effectively combined with other aviational forms. For example, a clearance form could be easily incorporated.

Recommendations

1. Establish the adequacy of the form by subjecting it to flight checks.

2. Determine the possibility of combining the form with other aviational forms.

3. Conduct studies to develop similar forms designed to meet the functional requirements of all types of aircraft on various missions."

353. *Specifications for a Navigation Chart for Use in High Speed, High Altitude Aircraft.
Reported by: Edward W. Bishop, Rolland H. Waters, and Jesse Orlansky
Office of Naval Research, Washington 25, D. C.
Contract No. N8onr-641
29 May 1951

"Problem

The purpose of this study was to develop production specifications for an aeronautical chart to be used for cross-country flight in high altitude, single-pilot aircraft. Current charts are inadequate for such flights because of the small area covered and the presentation of land marks which cannot be seen from high altitude.

Facts

1. A job analysis of the navigation procedures followed by pilots of high speed, high altitude aircraft was prepared using information obtained from interviews and a questionnaire.

2. Additional information was obtained from (a) an analysis of the effect of the operational characteristics of high altitude aircraft upon the task of navigating them and (b) a study to determine the objects which would be visible at high altitude.

Results

1. Functional requirements for a prototype-chart for cross-country flight in high speed, high altitude aircraft were derived from the job analysis of navigation at high altitude.

2. Production specifications for a chart which meets these functional requirements have been developed. The specifications are appended to this report.

3. Production of a prototype model of the chart, to be used for test purposes, was begun.

4. It was decided that proposed ground and flight checks should be conducted in order to compare the prototype chart with current charts.

Recommendations

1. Specifications for charts to be used by pilots of high speed, high altitude aircraft should be established on the basis of the evaluation tests and ground checks.

2. Similar procedures should be employed to develop charts for other purposes, such as approach and landing, for high altitude aircraft and other types of planes."

354. The *Development of Graphic Aids to Air Navigation
Reported by: John P. Kishler, Rolland H Waters, and Jesse Orlansky
Office of Naval Research, Washington 25, D. C.
Contract N8onr-641, Task Order 05
29 May 1951 (0)

"This report describes the first phase of an investigation directed toward the improvement of aeronautical charts. The results of the first year's work satisfy certain immediate as well as long term goals. For immediate use, a prototype-chart and a tabular navigation form have been developed to meet the needs of cross-country flight in high-altitude, high-speed, fighter-type aircraft. In addition, procedures have been established for developing new navigational charts for all types of flight and aircraft.

"The report consists of five chapters. Chapter I discusses the historical development of aeronautical charts and the need for improvement of present charts. Chapter II analyzes the features of existing cross-country aeronautical charts for high-altitude, high-speed navigation. Chapter III describes various studies conducted to produce an experimental aeronautical chart and an experimental navigational form. Chapter IV discusses the results of these studies. Chapter V presents conclusions and recommendations for future work on aeronautical charts."

355. The *Detectability of Yellows, Yellow-Reds, and Reds in Air-Sea Rescue
Florence L. Malone, Mary S. Sexton, and Dean Farnsworth
Medical Research Laboratory, U. S. Naval Submarine Base, New London, Connecticut
Medical Research Laboratory Report No. 182
Bureau of Medicine and Surgery, Navy Dept.
Project NM 003 041. 35. 01
Vol. 10, pp. 177-185 1951

"The effectiveness of the yellow currently used for lifesaving equipment as compared with a graduated series of yellows, yellow-reds, and reds (from 7.5 YR 7/8 to 5 R 7/8) was investigated.

"The experiment also investigated the use of a pair of chlorophyll detection goggles (1635 1/2 Eastman Kodak Company) as a means of increasing the visibility of the colors in this range.

"Observations were made outdoors in sunlight at distances of fifty to one hundred and thirty feet from the targets. The test colors were 1/4" circles mounted on blue-grey boards representing the color of the sea under three different weather conditions.

"The results indicate that the current yellow is a poor choice for lifesaving equipment, that orange-reds of the same brightness are more visible, and that the use of the 1635 1/2 detection goggle does not increase the visibility of the colors tested."

356. A Discussion of *Scale-Reading Habits
Kappauf, William E.
United States Air Force, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio. AF Technical Report No. 6569
July 1951

"This report brings together and summarizes various data on scale-reading habits which have been collected in the course of recent Princeton experiments on the design and use of instrument scales. Through an analysis of the conditions under which particular kinds of scale reading errors appear, explanations for these errors are sought in terms of habits and biases of the reader or the nature of the reading task. Evidence is also presented on the range of individual differences observed in scale reading situations, and an inquiry is made into the extent to which these differences may be predicted from simple pencil and paper tests or from previous measures of scale reading performance."

357. A *Comparison of Four Measures of Visual Discrimination of Shapes
Arnoult, Malcolm D., Gagne, Robert M., and Vanderplas, James M.
Human Resources Research Center, Lackland Air Force Base, San Antonio, Texas
Project No. 21-09-001 31 October 1951

"The task of discriminating between shapes is of basic importance in many Air Force jobs. For example, the need for a program of research on methods of training radar observers in shape discrimination and identification has been indicated. Of fundamental importance to a research program of this type is the development of methods and procedures for assessing accurately performance in discriminating shapes. Development of accurate measures is required in order that further research, directed toward outcome of more immediate application, can be grounded on a sound scientific basis.

"In this investigation pairs of irregular black shapes were presented, and airmen were required to judge whether the shapes were "Same" or "Different". Four methods of assessing performance in discriminating differences between the paired presentations were employed; between 40 and 50 subjects were used to obtain data on each method. The results indicate that measures based on the time required to respond "Same" or "Different" yield reliable differentiation among subjects, and that there is marked correspondence between such measures of discrimination between given pairs of shapes and the similarity of the respective pairs of shapes.

"This report will be of particular interest to research personnel engaged in work relating to problems of shape discrimination. The findings regarding methods for assessing performance in discriminating shapes have important implications with respect to research effort more directly associated with operational activities and requirements."

358. *Cue Attention Habits as a Factor in Training
Eckstrand, Gordon A.
United States Air Force, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio.
AF Technical Report No. 6566
August 1951

"Three groups of 40 subjects each learned a discriminative motor task which required that they associate four different response keys with four different colored forms. In this standard task both Color and Form were relevant cues, i.e., either stimulus aspect could be used to perform successfully on the task. Before learning this standard task, each of the groups had a different kind of preliminary training. Group A learned tasks in which Form was always relevant and Color always irrelevant. Group B learned tasks in which Color was always relevant and Form always irrelevant. Group C learned tasks in which both Form and Color were relevant. The forms and colors used in these preliminary tasks were different from those used in the standard task. In order to determine whether or not the preliminary training had a selective influence on which one of the relevant cues in the standard task was used to solve the problem, each of the groups was divided into two sub-groups. In each case one sub-group learned a test-task with only the forms from the standard task present and the other sub-group a test-task with only the standard task colors present. All learning was to a criterion. The test-task with only forms present was learned most rapidly by Group B. The situation was reversed in the learning of the test-task with only colors present. The results support the conclusion that cue attention habits established during training transfer to the learning of later, similar tasks. Implications for training device design are discussed."

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